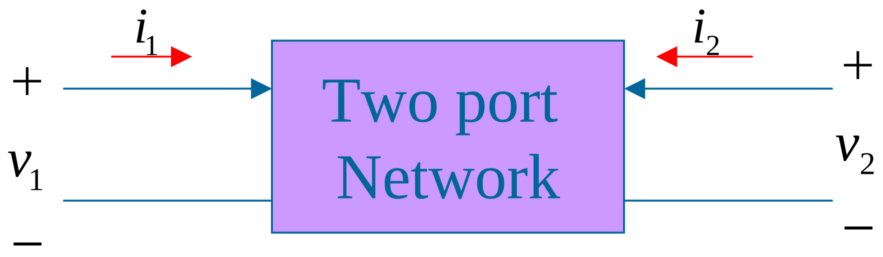
Lecture 14

Feedback

topics

- The series-shunt feedback
- The series-series feedback
- The shunt-shunt feedback
- The shunt-series feedback

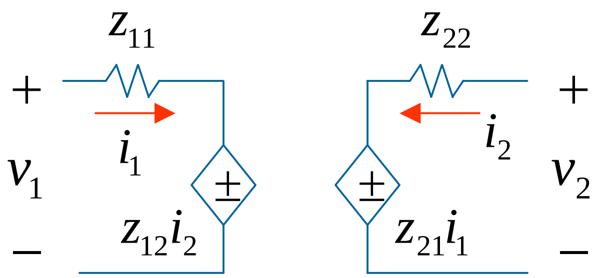
Two port networks



Type I: Impedance z-parameters

$$v_1 = f(i_1, i_2) = z_{11} i_1 + z_{12} i_2$$
$$v_2 = f(i_1, i_2) = z_{21} i_1 + z_{22} i_2$$

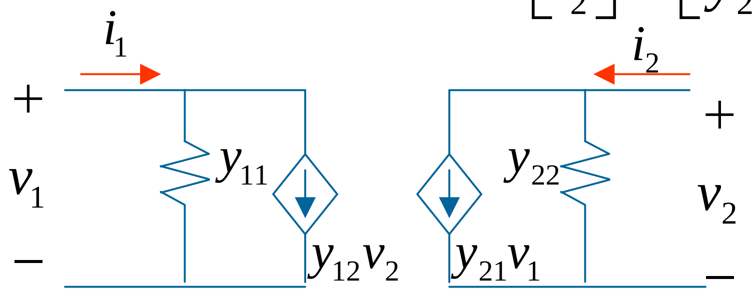
$$\Rightarrow \begin{bmatrix} v_1 \\ v_2 \end{bmatrix} = \begin{bmatrix} z_{11} & z_{12} \\ z_{21} & z_{22} \end{bmatrix} \begin{bmatrix} i_1 \\ i_2 \end{bmatrix}$$



Type II: Admittance y-parameters

$$i_1 = f(v_1, v_2) = y_{11}v_1 + y_{12}v_2$$
$$i_2 = f(v_1, v_2) = y_{21}v_1 + y_{22}v_2$$

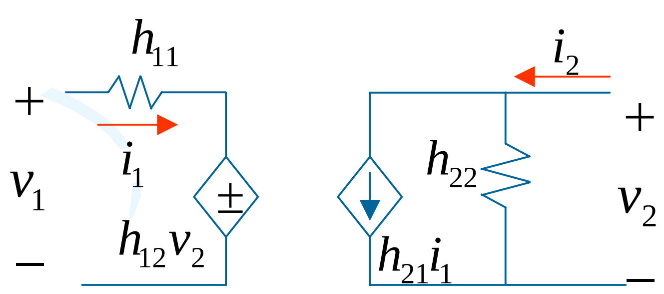
$$\Rightarrow \begin{bmatrix} i_1 \\ i_2 \end{bmatrix} = \begin{bmatrix} y_{11} & y_{12} \\ y_{21} & y_{22} \end{bmatrix} \begin{bmatrix} v_1 \\ v_2 \end{bmatrix}$$



Type III: hybrid h-parameters

$$v_1 = f(i_1, v_2) = h_{11}i_1 + h_{12}v_2$$
$$i_2 = f(i_1, v_2) = h_{21}i_1 + h_{22}v_2$$

$$\Rightarrow \begin{bmatrix} v_1 \\ i_2 \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix} \begin{bmatrix} i_1 \\ v_2 \end{bmatrix}$$

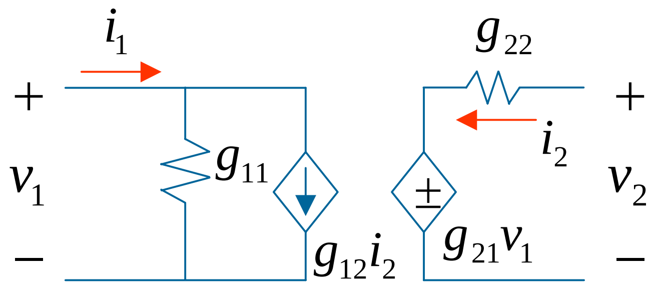


$$\begin{bmatrix} v_{be} \\ i_c \end{bmatrix} = \begin{bmatrix} h_{ie} & h_{re} \\ h_{fe} & h_{oe} \end{bmatrix} \begin{bmatrix} i_b \\ v_{ce} \end{bmatrix}$$

Type IV: Inverse-hybrid g-parameters

$$i_1 = f(v_1, i_2) = g_{11}v_1 + g_{12}i_2$$
$$v_2 = f(v_1, i_2) = g_{21}v_1 + g_{22}i_2$$

$$\Rightarrow \begin{bmatrix} i_1 \\ v_2 \end{bmatrix} = \begin{bmatrix} g_{11} & g_{12} \\ g_{21} & g_{22} \end{bmatrix} \begin{bmatrix} v_1 \\ i_2 \end{bmatrix}$$



Type V: transmission ABCD parameters

$$v_1 = f(v_2, -i_2) = Av_2 + B(-i_2)$$
$$i_1 = f(v_2, -i_2) = Cv_2 + D(-i_2)$$

$$\Rightarrow \begin{bmatrix} v_1 \\ i_1 \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} v_2 \\ -i_2 \end{bmatrix}$$

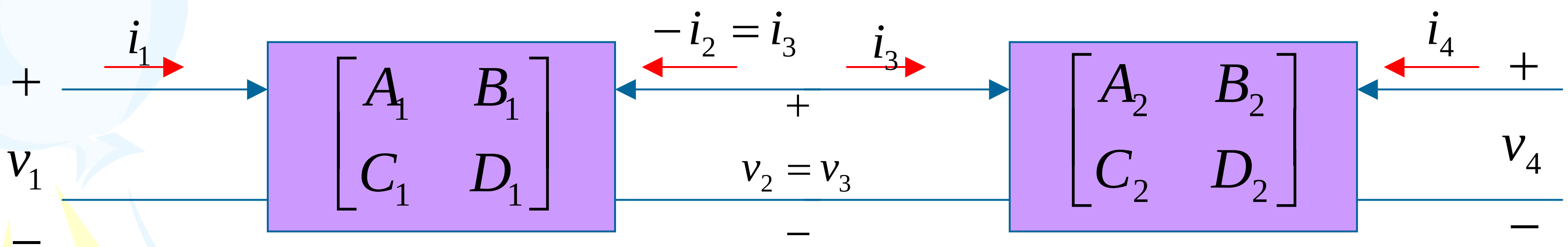
Type VI: Inverse transmission parameters

$$v_2 = f(v_1, -i_1) = A'v_1 + B'(-i_1)$$
$$i_2 = f(v_1, -i_1) = C'v_1 + D'(-i_1)$$

$$\Rightarrow \begin{bmatrix} v_2 \\ i_2 \end{bmatrix} = \begin{bmatrix} A' & B' \\ C' & D' \end{bmatrix} \begin{bmatrix} v_1 \\ -i_1 \end{bmatrix}$$

Two port Network combination:

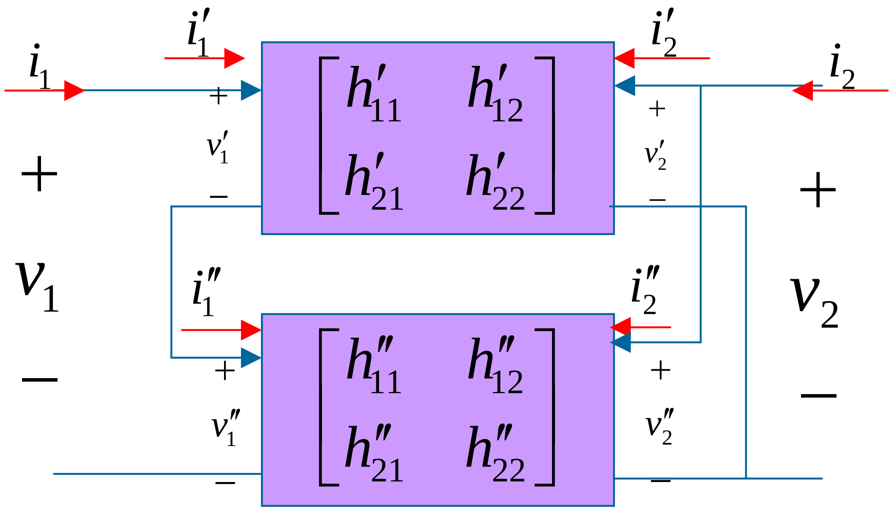
I. Cascade : ABCD parameters



$$\begin{bmatrix} v_1 \\ i_1 \end{bmatrix} = \begin{bmatrix} A_1 & B_1 \\ C_1 & D_1 \end{bmatrix} \begin{bmatrix} v_2 \\ -i_2 \end{bmatrix} \qquad \begin{bmatrix} v_3 \\ i_3 \end{bmatrix} = \begin{bmatrix} A_2 & B_2 \\ C_2 & D_2 \end{bmatrix} \begin{bmatrix} v_4 \\ -i_4 \end{bmatrix}$$

$$\begin{bmatrix} v_1 \\ i_1 \end{bmatrix} = \begin{bmatrix} A_1 & B_1 \\ C_1 & D_1 \end{bmatrix} \begin{bmatrix} A_2 & B_2 \\ C_2 & D_2 \end{bmatrix} \begin{bmatrix} v_4 \\ -i_4 \end{bmatrix}$$

II: series-shunt



$$i_1 = i_1' = i_1''$$

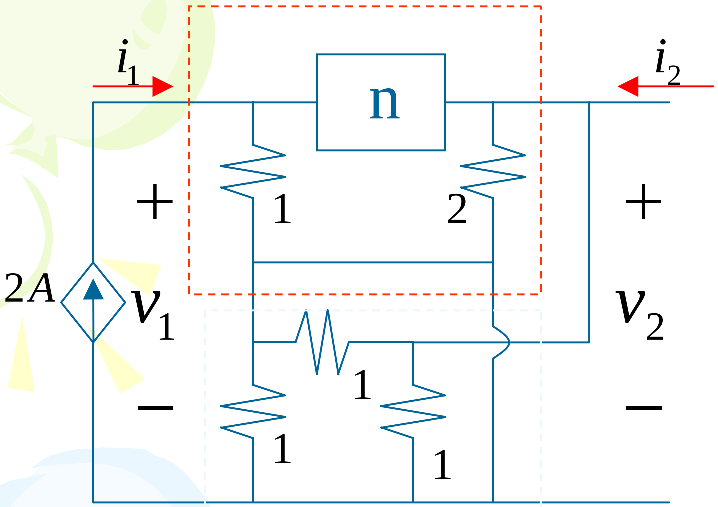
$$\boxed{\begin{aligned} v_1 &= v_1' + v_1'' \\ i_2 &= i_2' + i_2'' \end{aligned}}$$

$$v_2 = v_2' = v_2''$$

$$\begin{bmatrix} v_1' \\ i_2' \end{bmatrix} = \begin{bmatrix} h_{11}' & h_{12}' \\ h_{21}' & h_{22}' \end{bmatrix} \begin{bmatrix} i_1' \\ v_2' \end{bmatrix} \qquad \begin{bmatrix} v_1'' \\ i_2'' \end{bmatrix} = \begin{bmatrix} h_{11}'' & h_{12}'' \\ h_{21}'' & h_{22}'' \end{bmatrix} \begin{bmatrix} i_1'' \\ v_2'' \end{bmatrix}$$

$$\begin{bmatrix} v_1 \\ i_2 \end{bmatrix} = \begin{bmatrix} v_1' \\ i_2' \end{bmatrix} + \begin{bmatrix} v_1'' \\ i_2'' \end{bmatrix} = \left\{ \begin{bmatrix} h_{11}' & h_{12}' \\ h_{21}' & h_{22}' \end{bmatrix} + \begin{bmatrix} h_{11}'' & h_{12}'' \\ h_{21}'' & h_{22}'' \end{bmatrix} \right\} \begin{bmatrix} i_1 \\ v_2 \end{bmatrix}$$

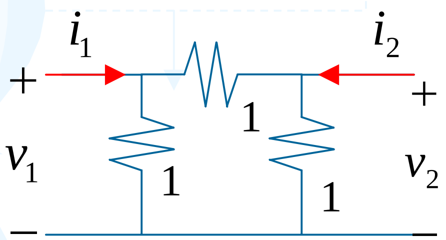
Ex:



$$h = \begin{bmatrix} 2 & 1 \\ 1 & 3 \end{bmatrix}$$

Find v_2=?

$$h_{total} = \begin{bmatrix} \frac{5}{2} & \frac{3}{2} \\ \frac{1}{2} & \frac{9}{2} \end{bmatrix}$$



$$v_1 = \frac{5}{2} i_1 + \frac{3}{2} v_2$$
$$i_2 = \frac{1}{2} i_1 + \frac{9}{2} v_2$$

$$\longrightarrow$$

$$i_1 = 2, i_2 = 0$$
$$v_2 = -\frac{2}{9}$$

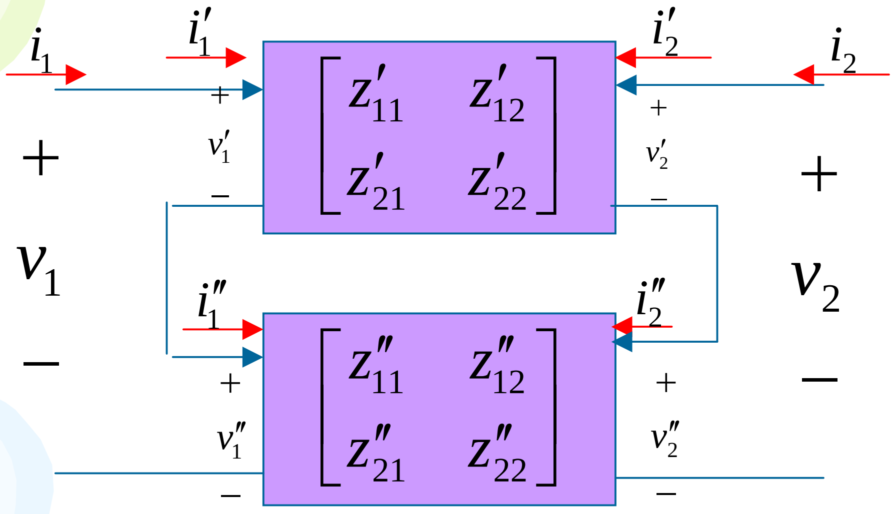
$$i_1 = \frac{v_1}{1} + \frac{v_1 - v_2}{1} \Rightarrow v_1 = \frac{1}{2} i_1 + \frac{1}{2} v_2$$

$$i_2 = \frac{v_2}{1} + \frac{v_2 - v_1}{1} \Rightarrow i_2 = -v_1 + 2v_2$$

$$i_2 = -v_1 + 2v_2 = -\frac{1}{2} i_1 + \frac{3}{2} v_2$$

$$\Rightarrow \quad h = \begin{bmatrix} \frac{1}{2} & \frac{1}{2} \\ -\frac{1}{2} & \frac{3}{2} \end{bmatrix}$$

III: series-series



$$i_1 = i_1' = i_1''$$

$$\boxed{v_1 = v_1' + v_1''}$$

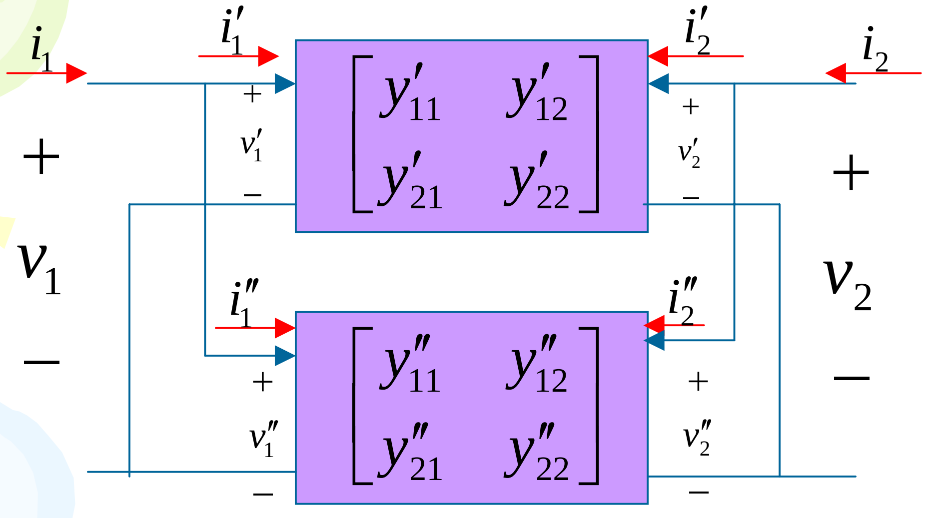
$$i_2 = i_2' = i_2''$$

$$\boxed{v_2 = v_2' + v_2''}$$

$$\begin{bmatrix} v_1' \\ v_2' \end{bmatrix} = \begin{bmatrix} z_{11}' & z_{12}' \\ z_{21}' & z_{22}' \end{bmatrix} \begin{bmatrix} i_1' \\ i_2' \end{bmatrix} \qquad \begin{bmatrix} v_1'' \\ v_2'' \end{bmatrix} = \begin{bmatrix} z_{11}'' & z_{12}'' \\ z_{21}'' & z_{22}'' \end{bmatrix} \begin{bmatrix} i_1'' \\ i_2'' \end{bmatrix}$$

$$\begin{bmatrix} v_1 \\ v_2 \end{bmatrix} = \begin{bmatrix} v_1' \\ v_2' \end{bmatrix} + \begin{bmatrix} v_1'' \\ v_2'' \end{bmatrix} = \left\{ \begin{bmatrix} z_{11}' & z_{12}' \\ z_{21}' & z_{22}' \end{bmatrix} + \begin{bmatrix} z_{11}'' & z_{12}'' \\ z_{21}'' & z_{22}'' \end{bmatrix} \right\} \begin{bmatrix} i_1 \\ i_2 \end{bmatrix}$$

IV: Shunt-shunt



$$\boxed{i_1 = i_1' + i_1''}$$

$$v_1 = v_1' = v_1''$$

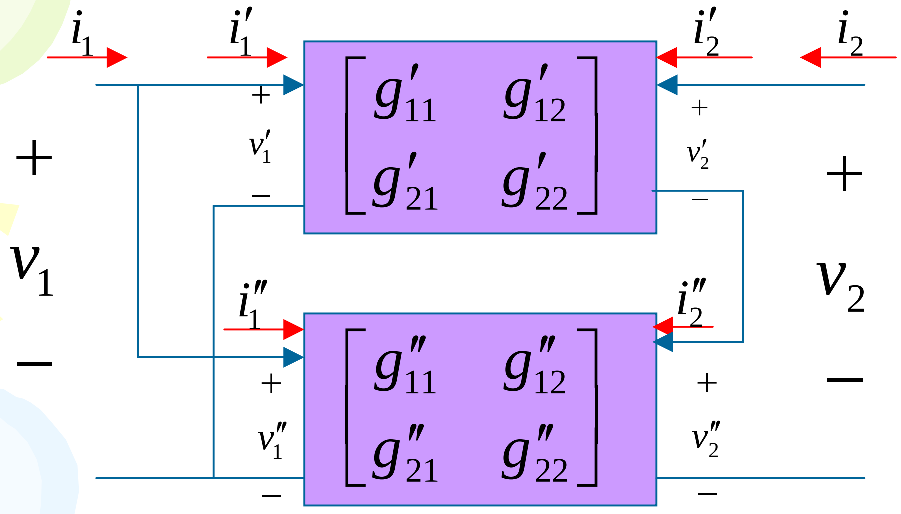
$$\boxed{i_2 = i_2' + i_2''}$$

$$v_2 = v_2' = v_2''$$

$$\begin{bmatrix} i_1' \\ i_2' \end{bmatrix} = \begin{bmatrix} y_{11}' & y_{12}' \\ y_{21}' & y_{22}' \end{bmatrix} \begin{bmatrix} v_1' \\ v_2' \end{bmatrix} \qquad \begin{bmatrix} i_1'' \\ i_2'' \end{bmatrix} = \begin{bmatrix} y_{11}'' & y_{12}'' \\ y_{21}'' & y_{22}'' \end{bmatrix} \begin{bmatrix} v_1'' \\ v_2'' \end{bmatrix}$$

$$\begin{bmatrix} i_1 \\ i_2 \end{bmatrix} = \begin{bmatrix} i_1' \\ i_2' \end{bmatrix} + \begin{bmatrix} i_1'' \\ i_2'' \end{bmatrix} = \left\{ \begin{bmatrix} y_{11}' & y_{12}' \\ y_{21}' & y_{22}' \end{bmatrix} + \begin{bmatrix} y_{11}'' & y_{12}'' \\ y_{21}'' & y_{22}'' \end{bmatrix} \right\} \begin{bmatrix} v_1 \\ v_2 \end{bmatrix}$$

V: shunt-series



$$\boxed{i_1 = i_1' + i_1''}$$

$$v_1 = v_1' = v_1''$$

$$i_2 = i_2' = i_2''$$

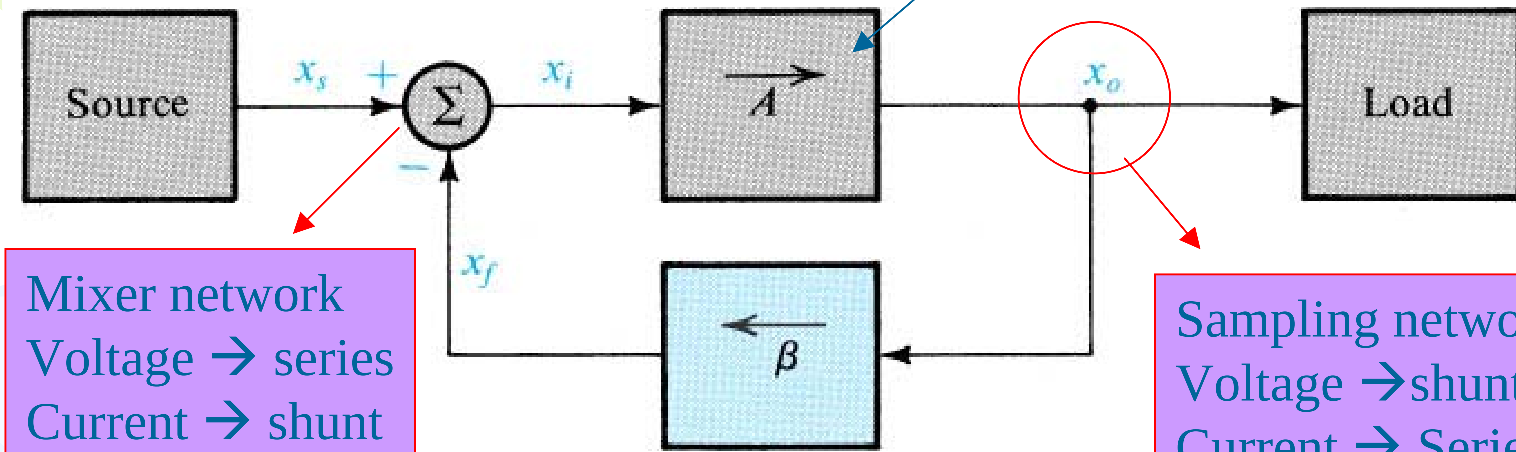
$$\boxed{v_2 = v_2' + v_2''}$$

$$\begin{bmatrix} i_1' \\ v_2' \end{bmatrix} = \begin{bmatrix} g'_{11} & g'_{12} \\ g'_{21} & g'_{22} \end{bmatrix} \begin{bmatrix} v_1' \\ i_2' \end{bmatrix} \qquad \begin{bmatrix} i_1'' \\ v_2'' \end{bmatrix} = \begin{bmatrix} g''_{11} & g''_{12} \\ g''_{21} & g''_{22} \end{bmatrix} \begin{bmatrix} v_1'' \\ i_2'' \end{bmatrix}$$

$$\begin{bmatrix} i_1 \\ v_2 \end{bmatrix} = \begin{bmatrix} i_1' \\ v_2' \end{bmatrix} + \begin{bmatrix} i_1'' \\ v_2'' \end{bmatrix} = \left\{ \begin{bmatrix} g'_{11} & g'_{12} \\ g'_{21} & g'_{22} \end{bmatrix} + \begin{bmatrix} g''_{11} & g''_{12} \\ g''_{21} & g''_{22} \end{bmatrix} \right\} \begin{bmatrix} v_1 \\ i_2 \end{bmatrix}$$

General feedback structure

Open loop gain



Mixer network
Voltage → series
Current → shunt

Sampling network
Voltage →shunt
Current → Series

$A\beta$ → Loop gain

$$x_o = Ax_i$$

$$x_f = \beta x_o$$

$$x_i = x_s - x_f$$

$$A_f \equiv \frac{x_o}{x_s} = \frac{A}{1 + A\beta}$$ Closed-loop gain

Negative feedback properties

- Gain desensitivity
- Bandwidth extension
- Noise reduction
- Nonlinear distortion reduction

1.Gain desensitivity

$$A_f \equiv \frac{x_o}{x_s} = \frac{A}{1+A\beta}$$

$$\boxed{\frac{dA_f}{A_f} < \frac{dA}{A}}$$

$$dA_f = \frac{dA}{(1+A\beta)^2}$$

$$\frac{dA_f}{A_f} = \frac{1}{1+A\beta}\frac{dA}{A}$$

2.Bandwidth extension

$$\boxed{BW = \omega_{Hf} - \omega_{Lf}}$$

$$A(s) = \frac{A_M \omega_H}{\omega_H + s} = \frac{A_M}{1+s/\omega_H}$$

$$A_f(s) = \frac{A(s)}{1+\beta A(s)} = \frac{A_M/(1+\beta A_M)}{1+s/\omega_H(1+\beta A_M)}$$

$$\omega_{Hf} = \omega_H(1+\beta A_M)$$

$$A(s) = \frac{A_M s}{\omega_L + s} = \frac{A_M}{1+\omega_L/s}$$

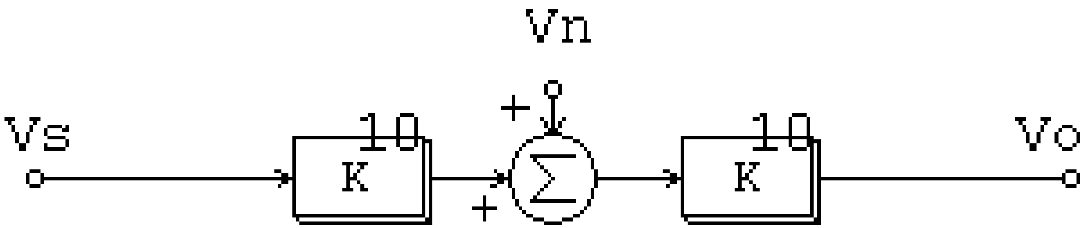
$$A_f(s) = \frac{A(s)}{1+\beta A(s)}$$

$$\omega_{Lf} = \omega_L/(1+\beta A_M)$$

3.Noise reduction

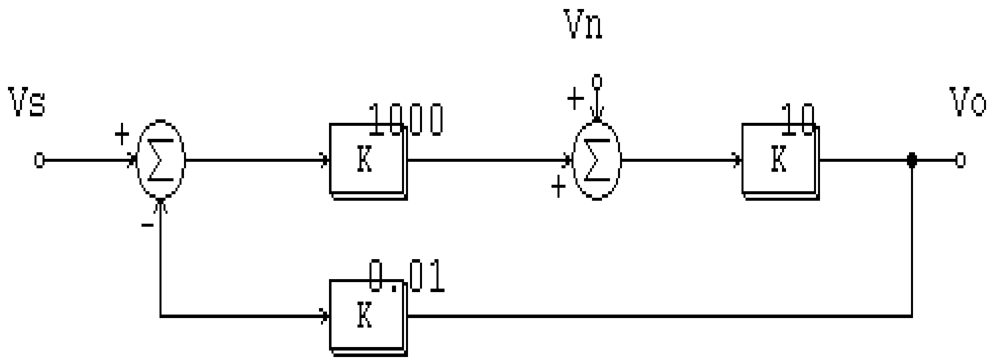
$$SNR = \frac{S}{N}$$

(S*ignal* to Noise Ratio)

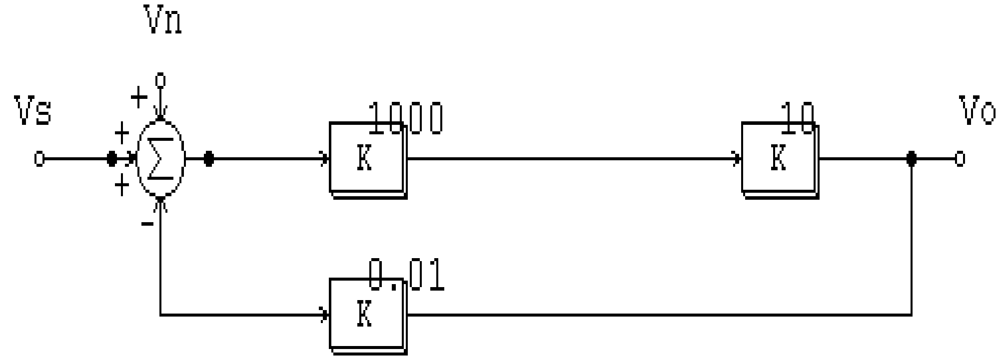


$$V_o = (10V_s + V_n)10$$

$$\frac{S}{N} = \frac{100V_s}{10V_n} = 10\frac{S}{N}$$



$$V_o = \frac{10}{1+100} V_n + \frac{10000}{1+100} V_s$$
$$= 0.1\mathrm{V}_n + 100\mathrm{V}_s$$
$$\frac{\mathrm{S}}{\mathrm{N}} = 1000\,\frac{\mathrm{S}}{\mathrm{N}}$$



$$V_o = 10000\,(V_s - 0.01V_o + V_n)$$
$$\Rightarrow V_o = 100V_s + 100V_n$$
$$\frac{\mathrm{S}}{\mathrm{N}} = 1\times\frac{\mathrm{S}}{\mathrm{N}}$$

4.Nonlinear distortion reduction

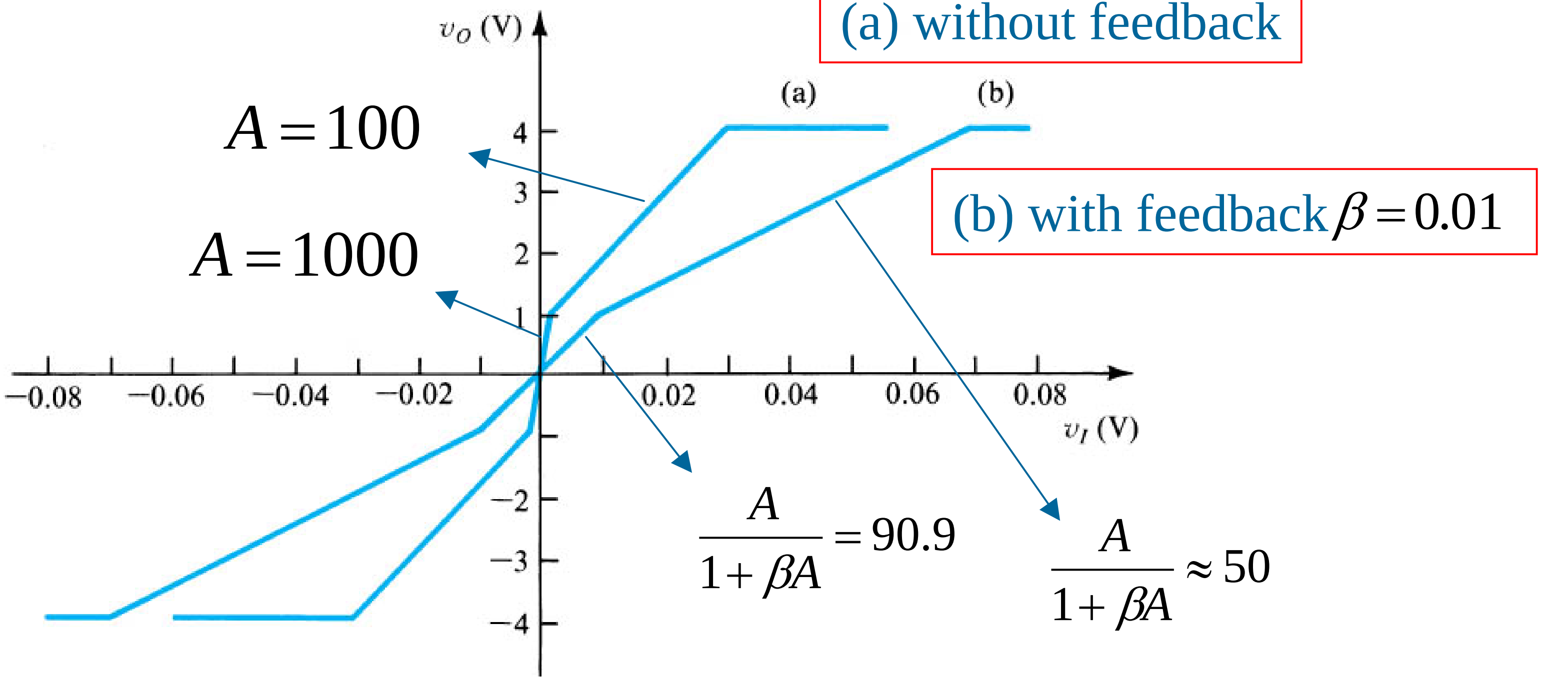
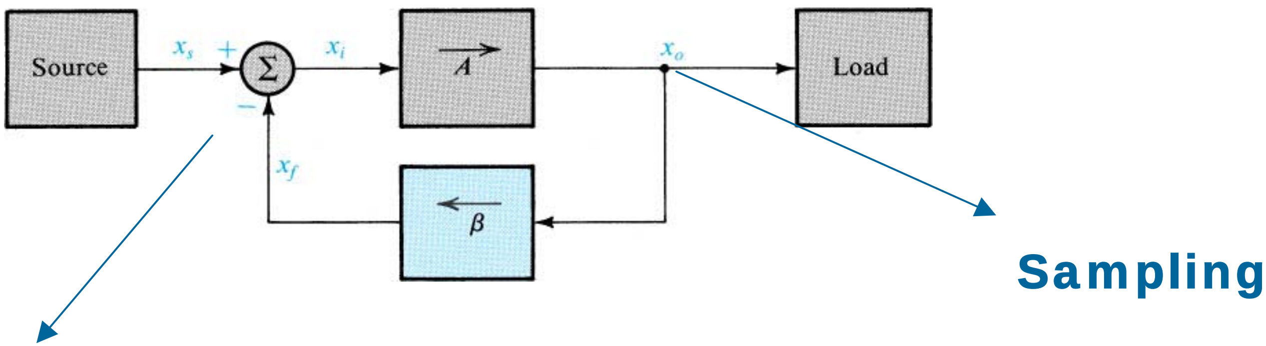
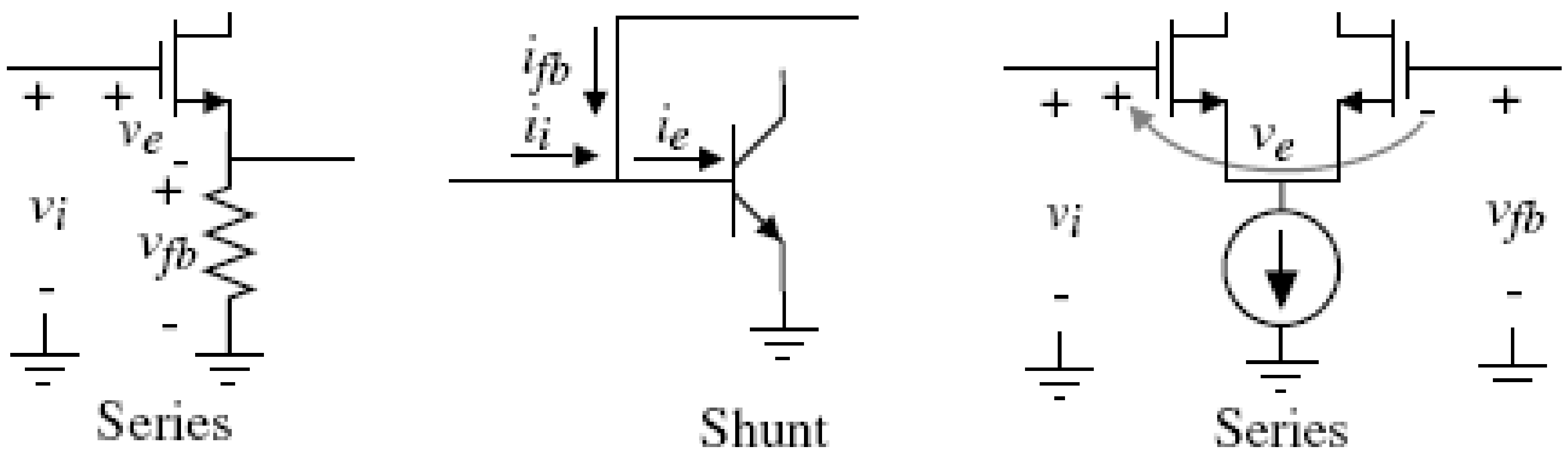


Figure 8.3 Illustrating the application of negative feedback to reduce the nonlinear distortion in amplifiers. Curve (a) shows the amplifier transfer characteristic without feedback. Curve (b) shows the characteristic with negative feedback ($\beta = 0.01$) applied.

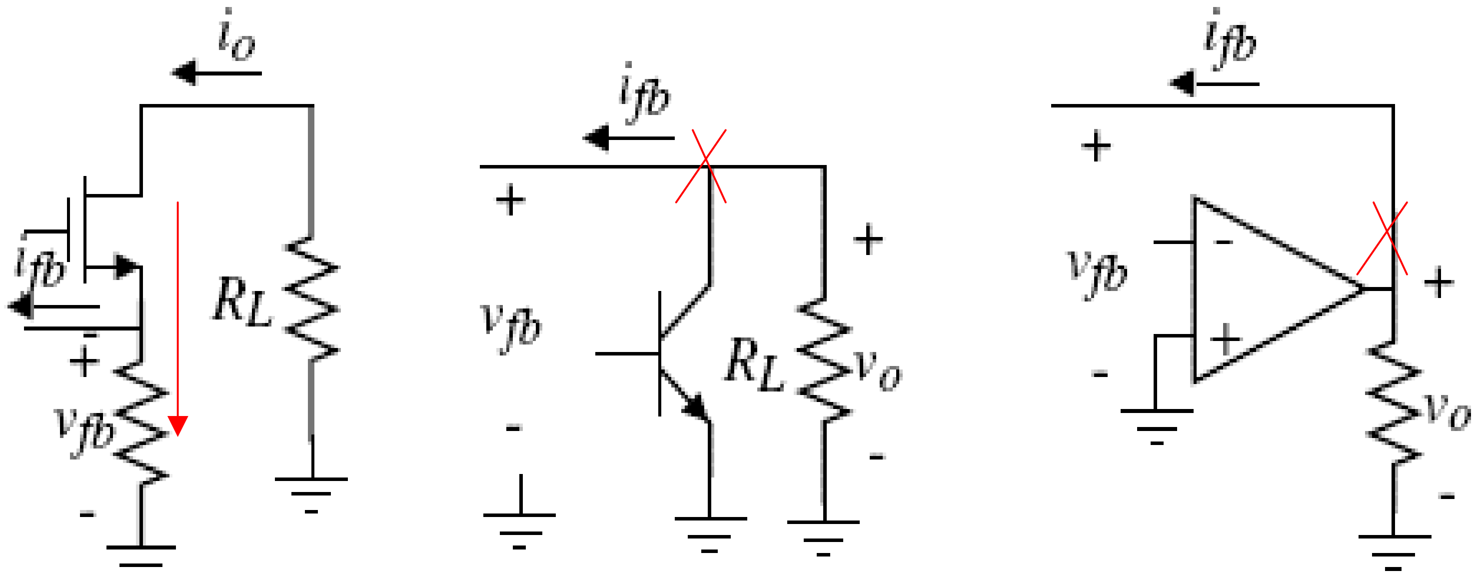
Feedback Topology



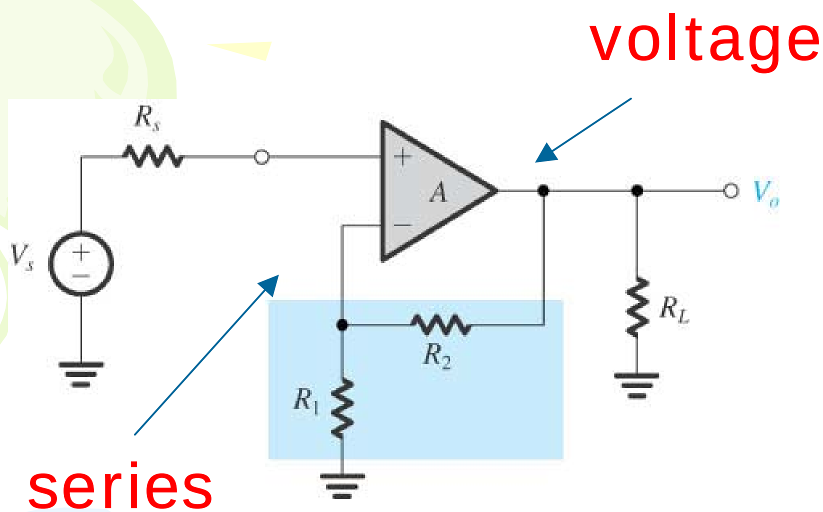
Mixer network: Voltage → series Current → shunt

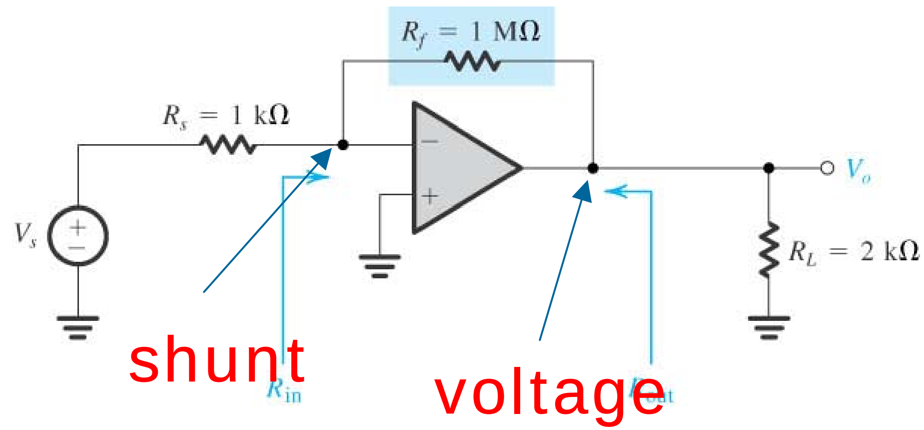


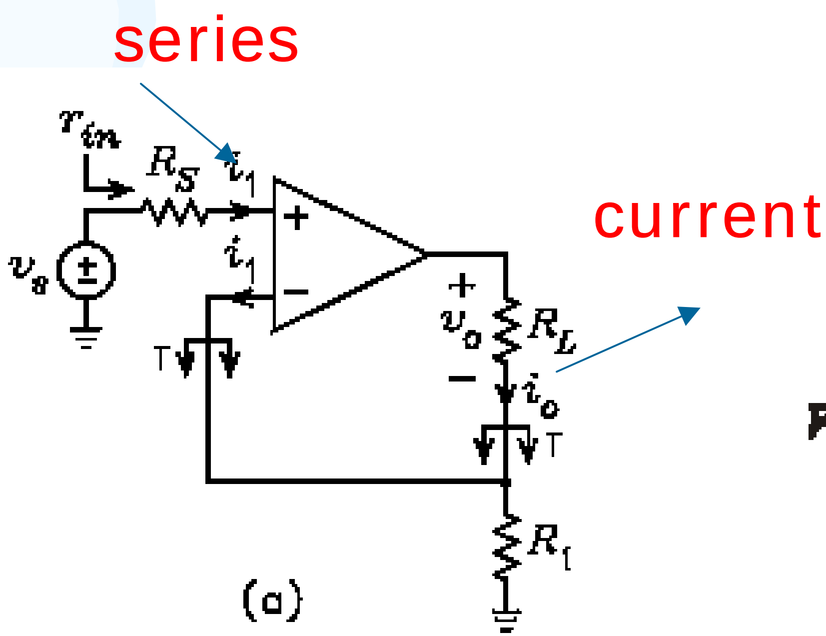
Sampling network : Voltage →shunt Current → Series

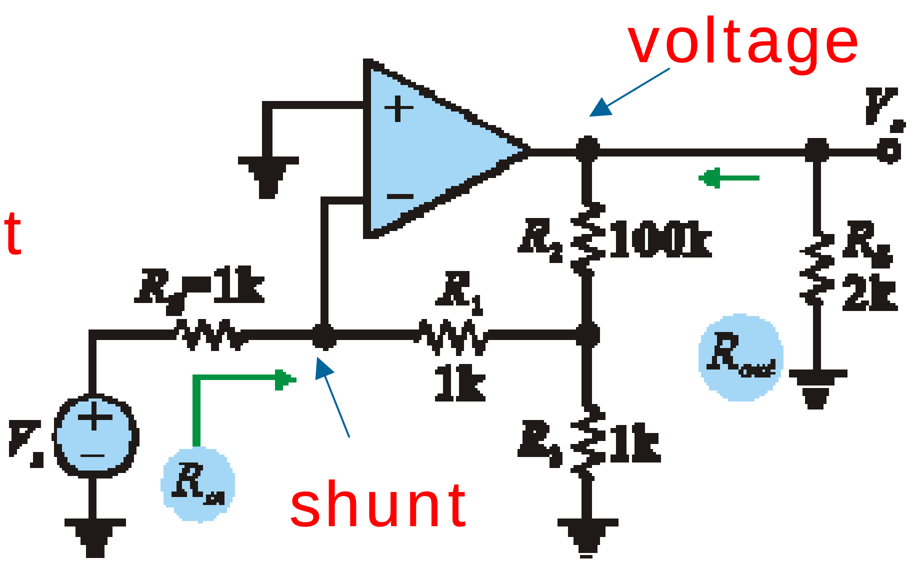


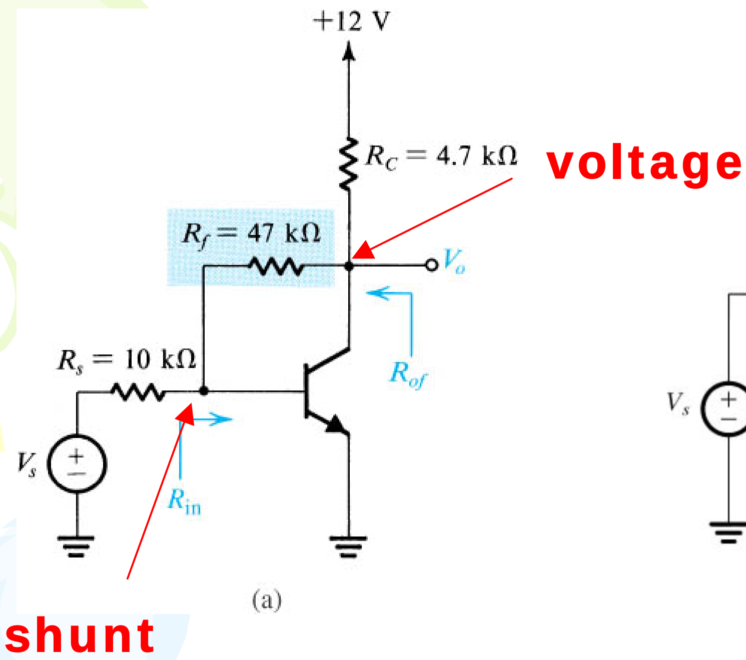
Series Shunt Shunt

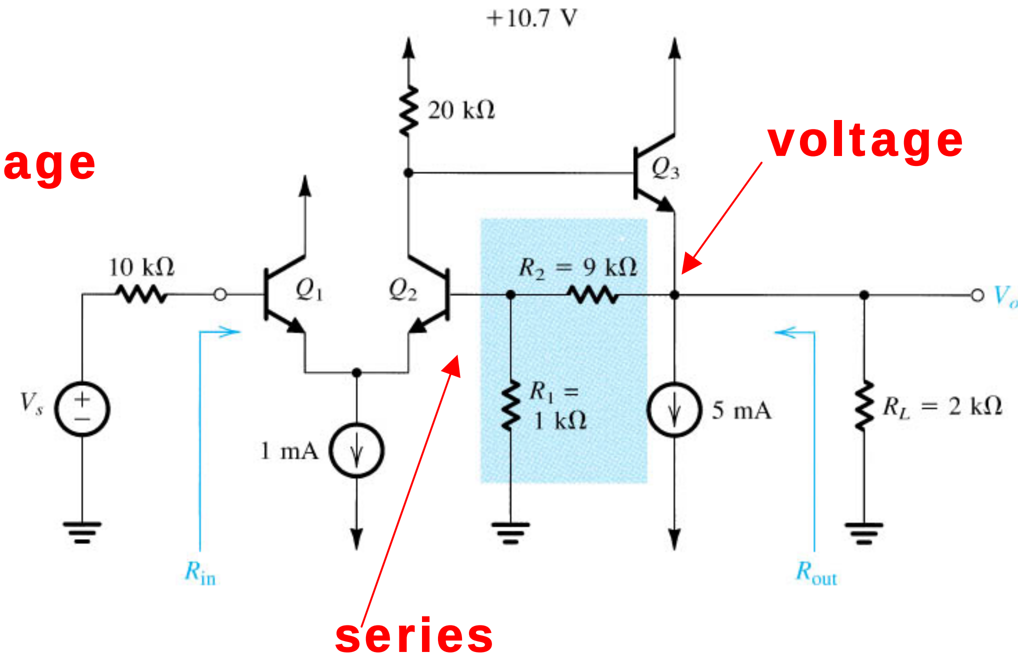

voltage
R_s
A
V_s
V_o
R_L
R_2
R_1
series

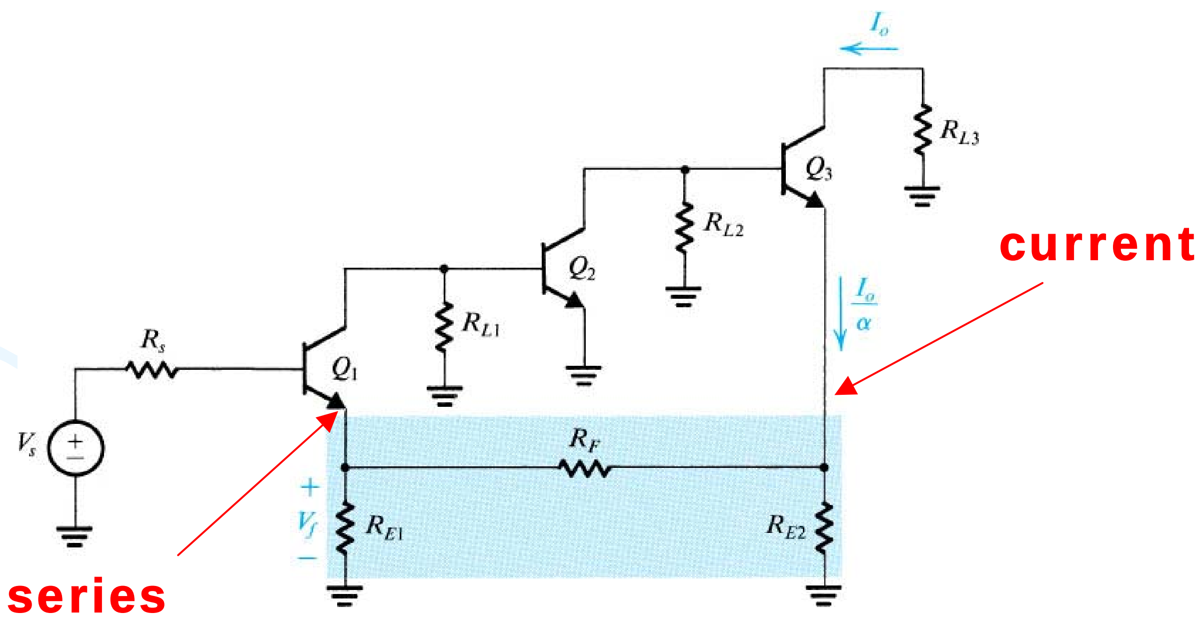

R_f = 1 MΩ
R_s = 1 kΩ
V_s
V_o
R_L = 2 kΩ
shunt
R_{in}
voltage
R_{out}

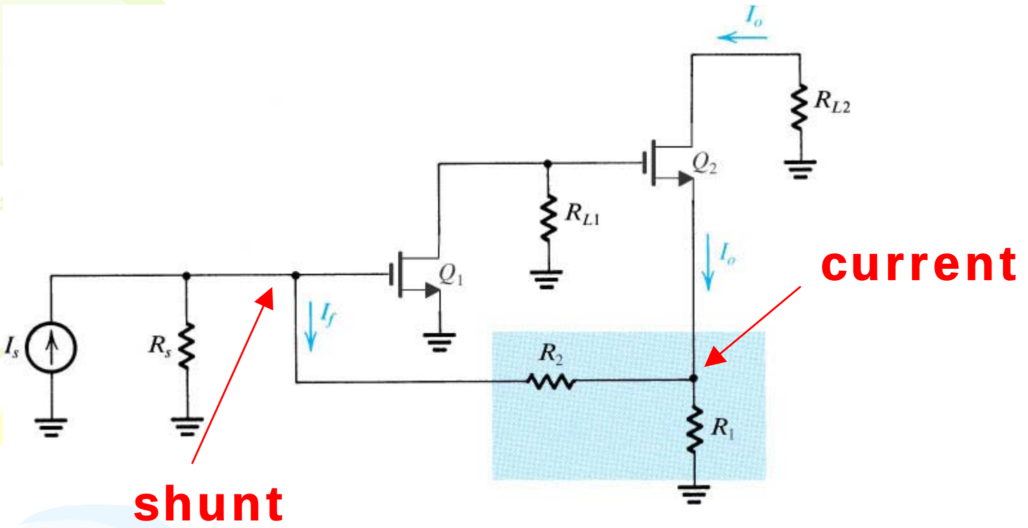

series
r_{in}
R_S
i_1
v_s
v_o
R_L
i_o
R_1
current
(a)


voltage
V_o
R_2 100k
R_s=1k
R_1
1k
R_L
2k
R_{out}
V_s
R_{in}
R_3 1k
shunt


+12 V
R_C = 4.7 kΩ
voltage
R_f = 47 kΩ
V_o
R_{of}
R_s = 10 kΩ
V_s
R_{in}
shunt
(a)


+10.7 V
20 kΩ
Q_3
voltage
10 kΩ
Q_1
Q_2
R_2 = 9 kΩ
V_o
V_s
R_1 = 1 kΩ
5 mA
R_L = 2 kΩ
1 mA
R_{in}
R_{out}
series


I_o
R_{L3}
Q_3
R_{L2}
current
Q_2
$\frac{I_o}{\alpha}$
R_{L1}
R_s
Q_1
V_s
R_F
+
V_f
−
R_{E1}
R_{E2}
series



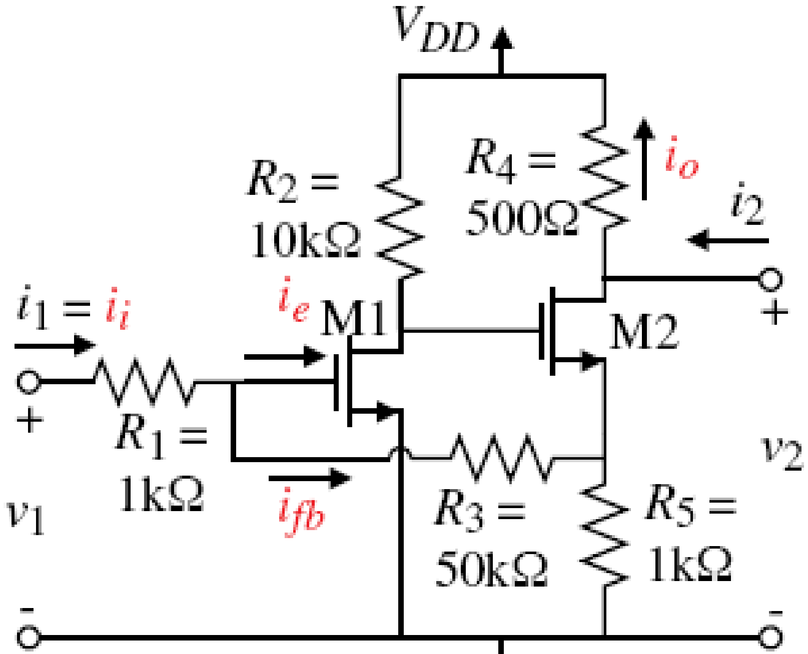


Fig. 280-07

Shunt series

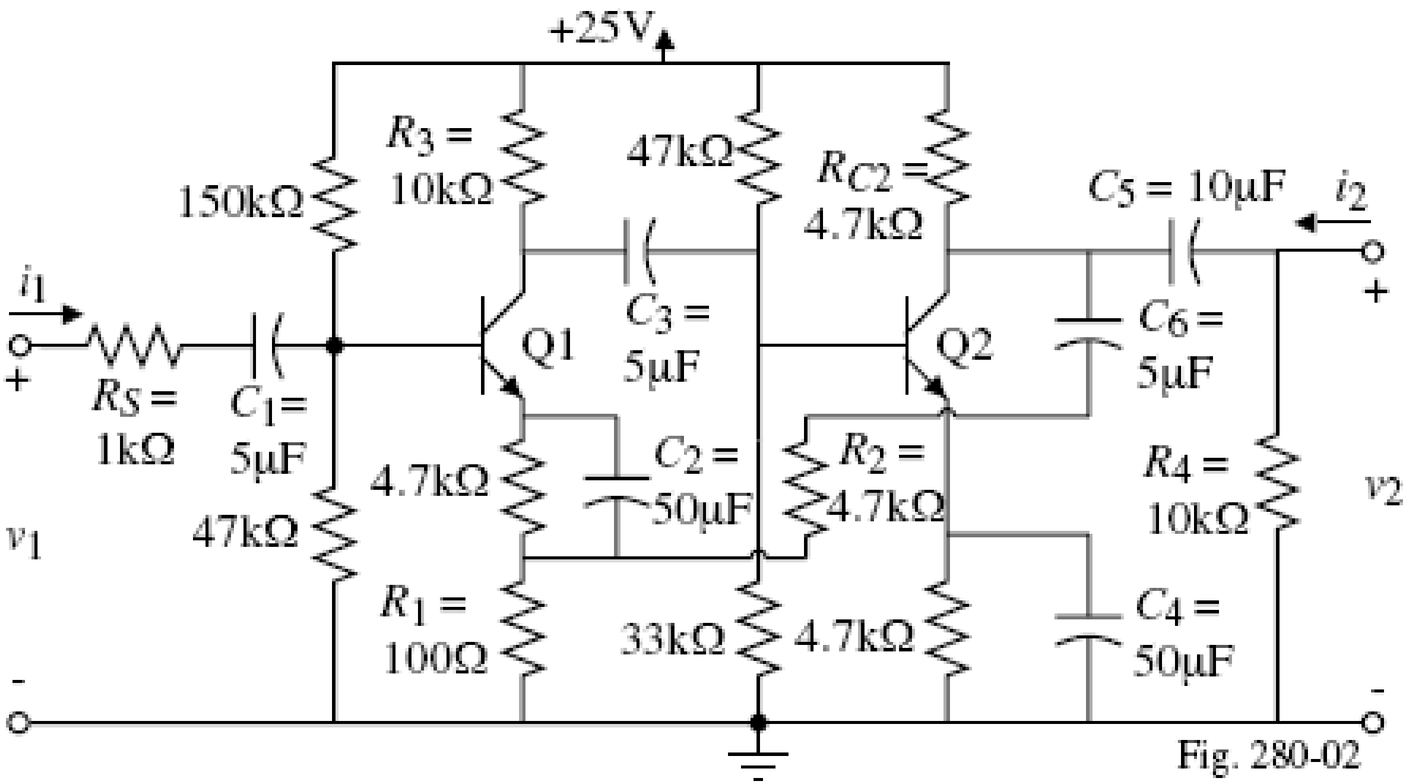
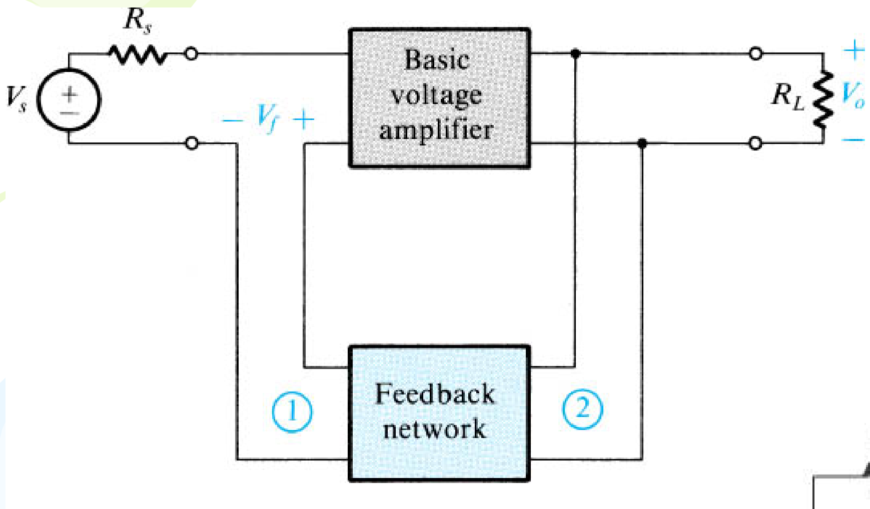


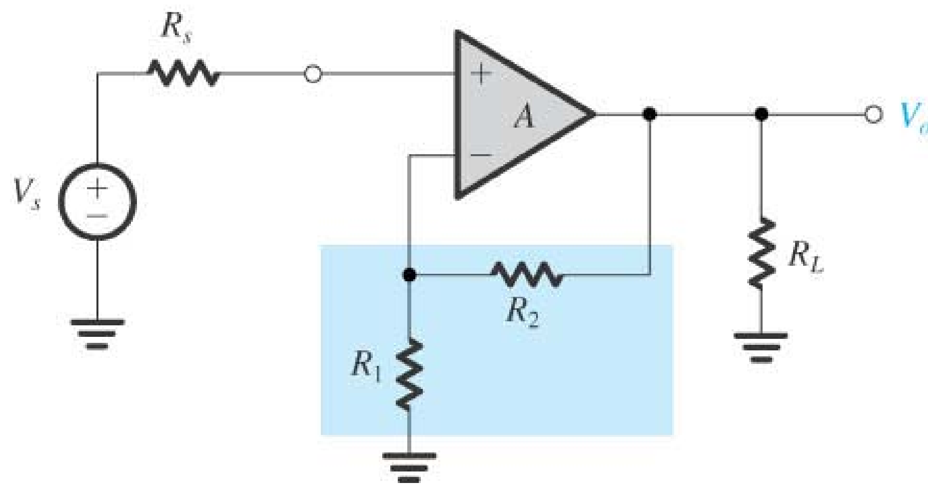
Fig. 280-02

Series- shunt

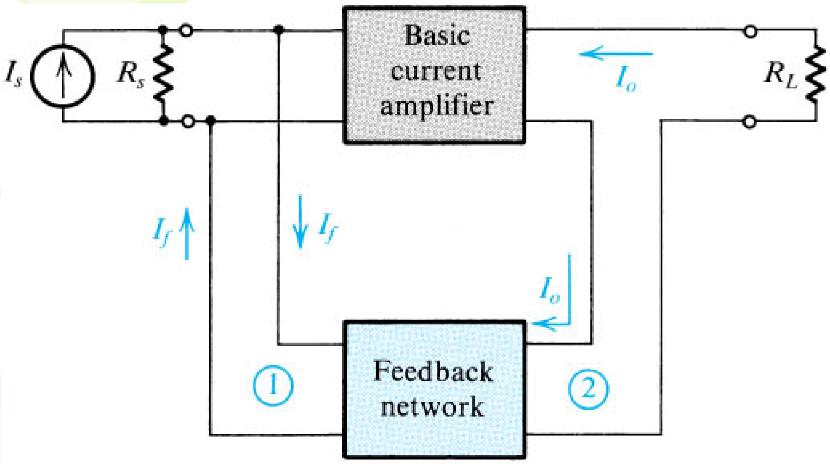
voltage-mixing voltage-sampling (series–shunt) topology



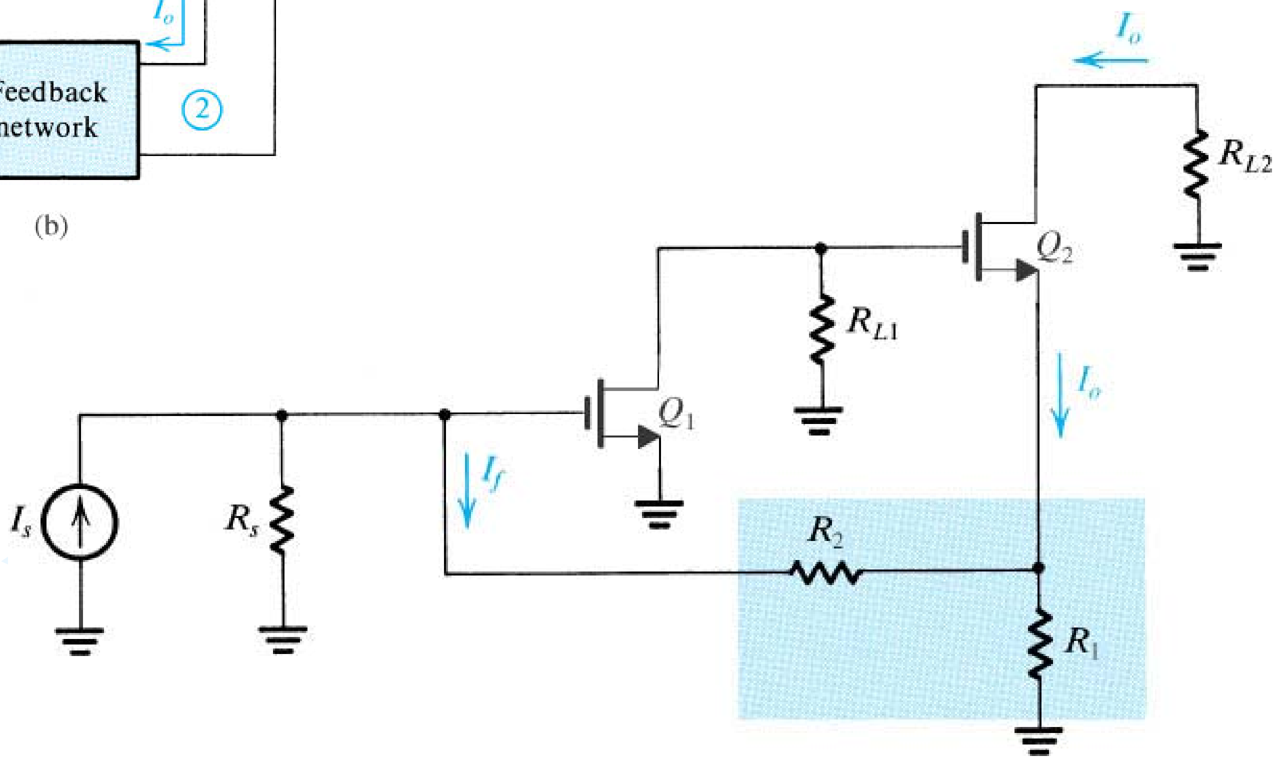
(a)



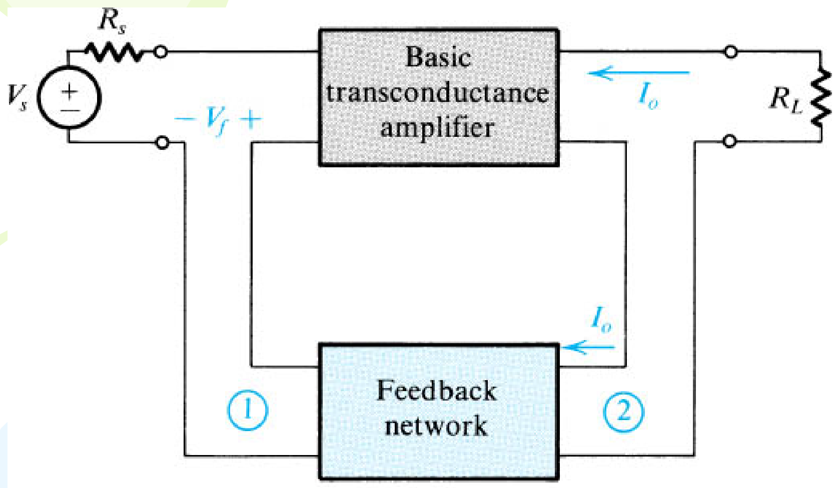
current-mixing current-sampling (shunt–series) topology



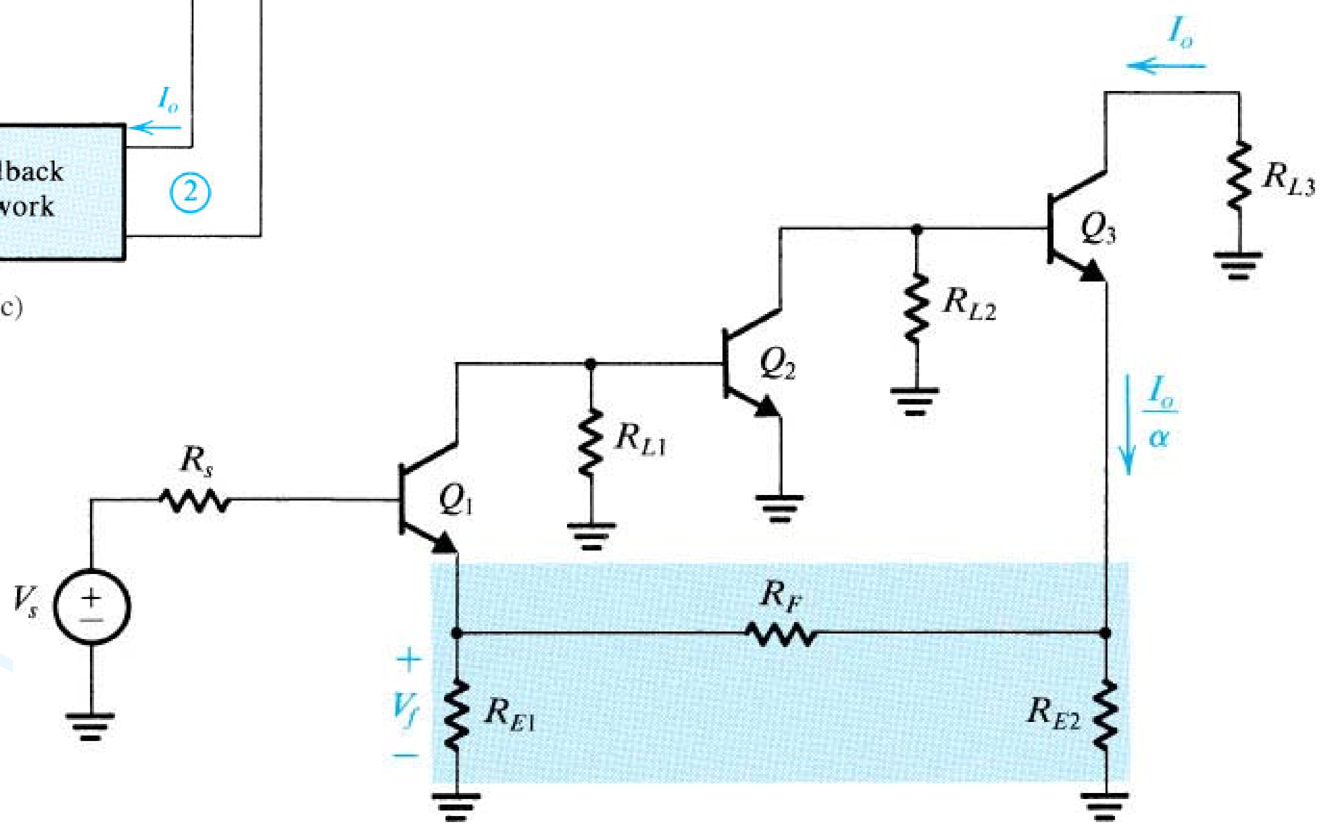
(b)



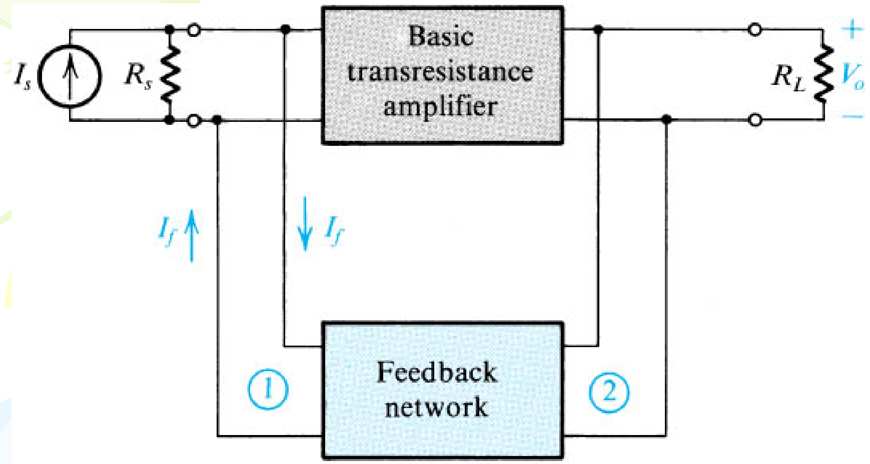
voltage-mixing current-sampling (series–series) topology



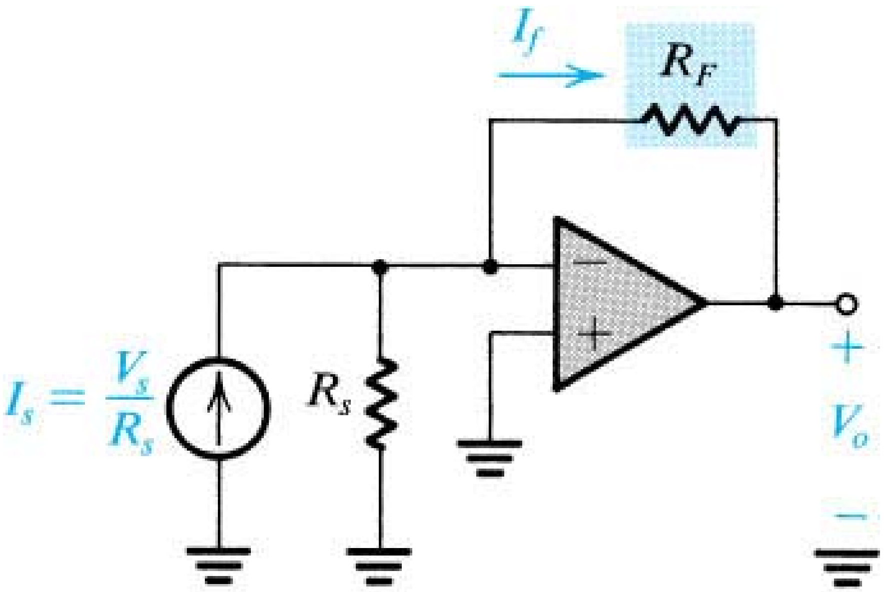
(c)



current-mixing voltage-sampling (shunt–shunt) topology

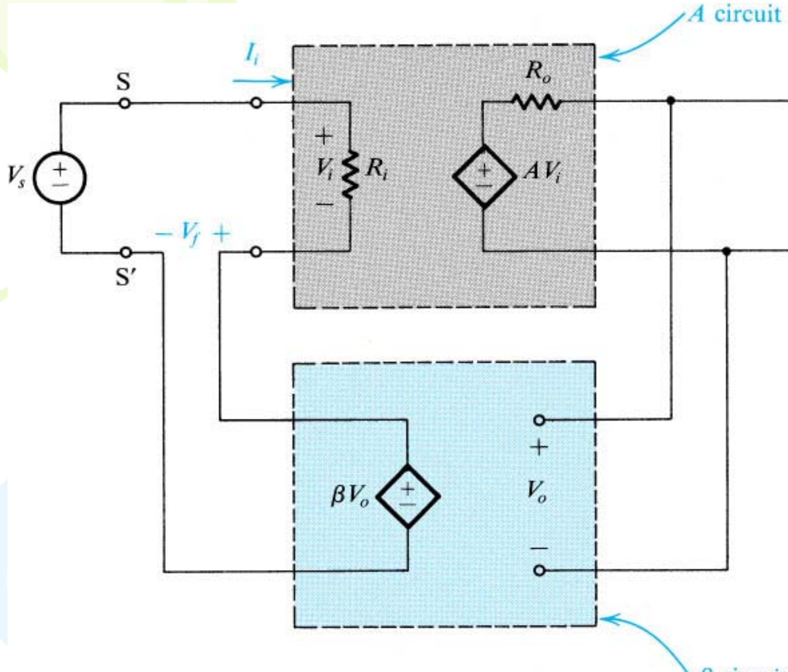


(d)

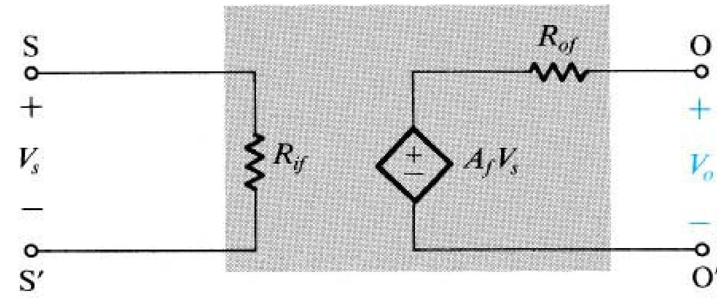


(b)

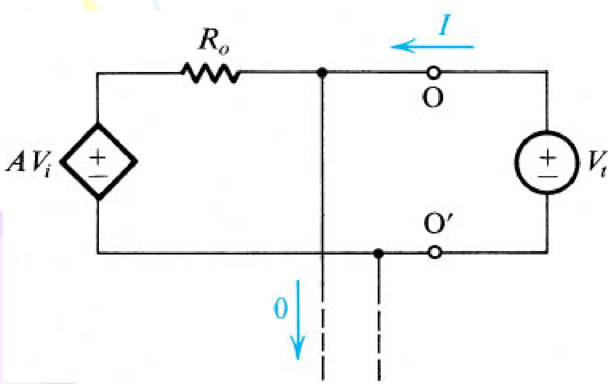
The series–shunt feedback amplifier



(a)



(b)



$$A_f \equiv \frac{V_o}{V_s} = \frac{A}{1+\beta A}$$

$$R_{if} \equiv \frac{V_s}{I_i} = \frac{V_i + \beta V_o}{V_i / R_i} = \frac{V_i + \beta A V_i}{V_i / R_i} = R_i(1+\beta A)$$

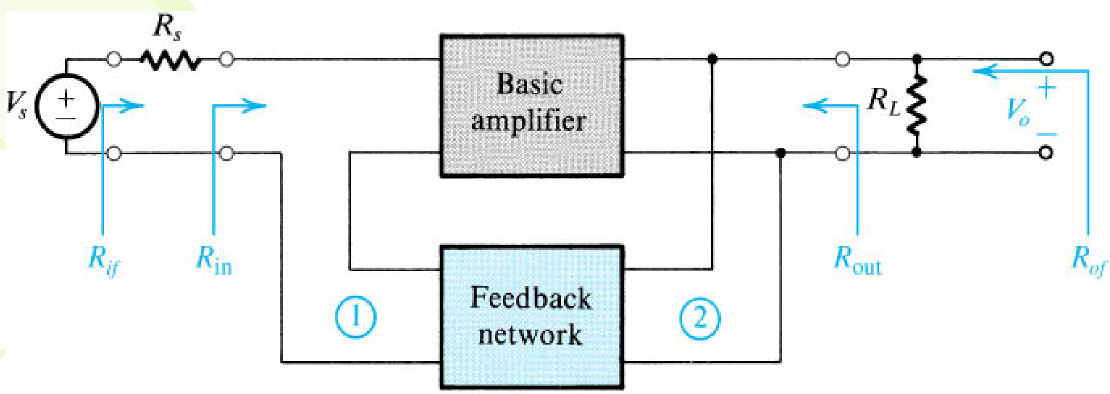
$$R_{if} = R_i(1+\beta A)$$

$$R_{of} \equiv \frac{V_o}{I_o}\bigg|_{V_s=0}$$

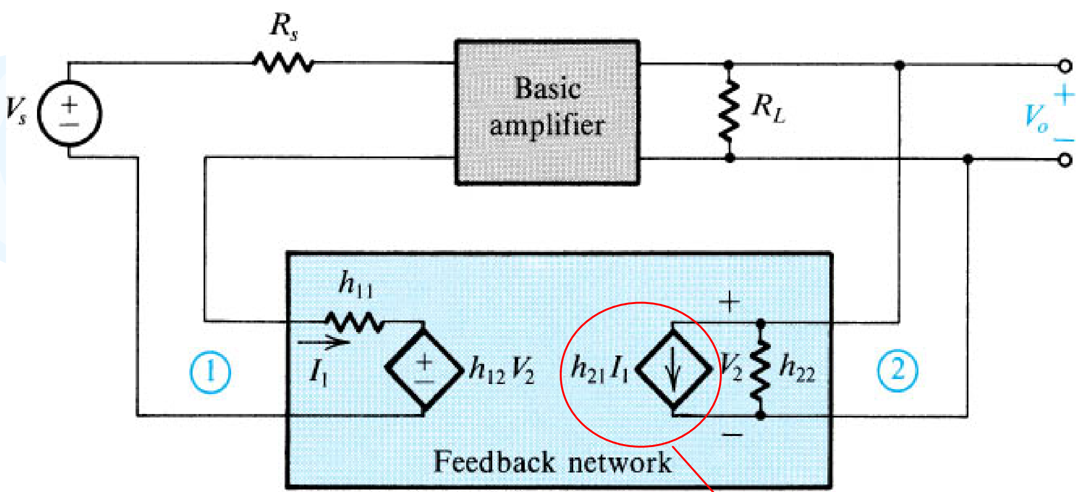
$$I_o = \frac{V_o - AV_i}{R_o}$$

$$V_i\big|_{V_s=0} = -\beta V_o$$

$$I = \frac{V_o + \beta A V_o}{R_o} \Rightarrow R_{of} = \frac{R_o}{1+\beta A}$$



(a)



(b)

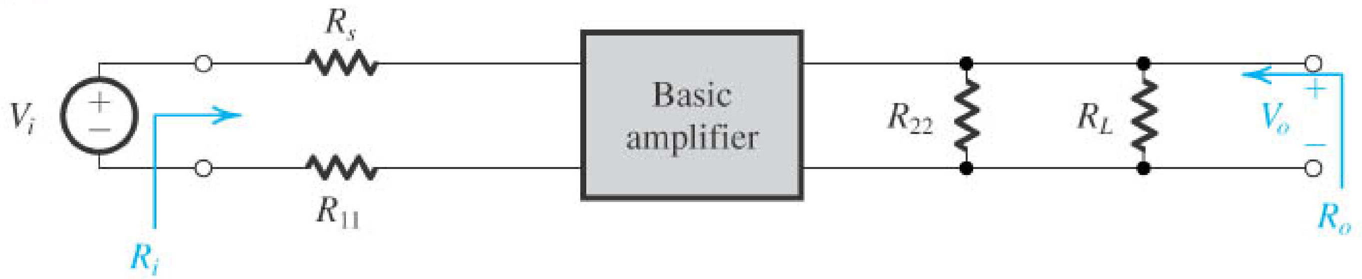
$$V_1 = h_{11}I_1 + h_{12}V_2$$

$$I_2 = h_{21}I_1 + h_{22}V_2$$

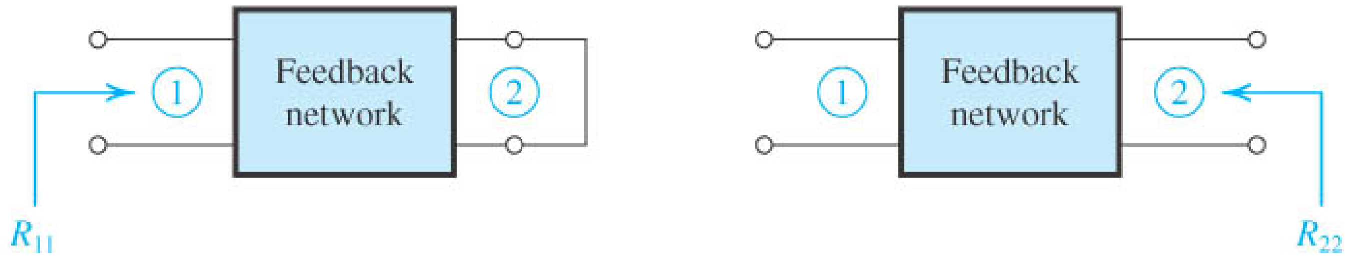
$$\begin{bmatrix} V_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix} \begin{bmatrix} I_1 \\ V_2 \end{bmatrix}$$

Passive network h_{21} tends to zero

(a) The A circuit is

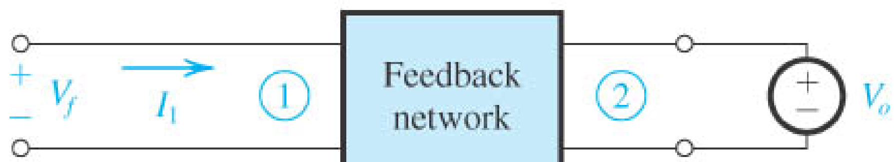


where R_{11} is obtained from and R_{22} is obtained from



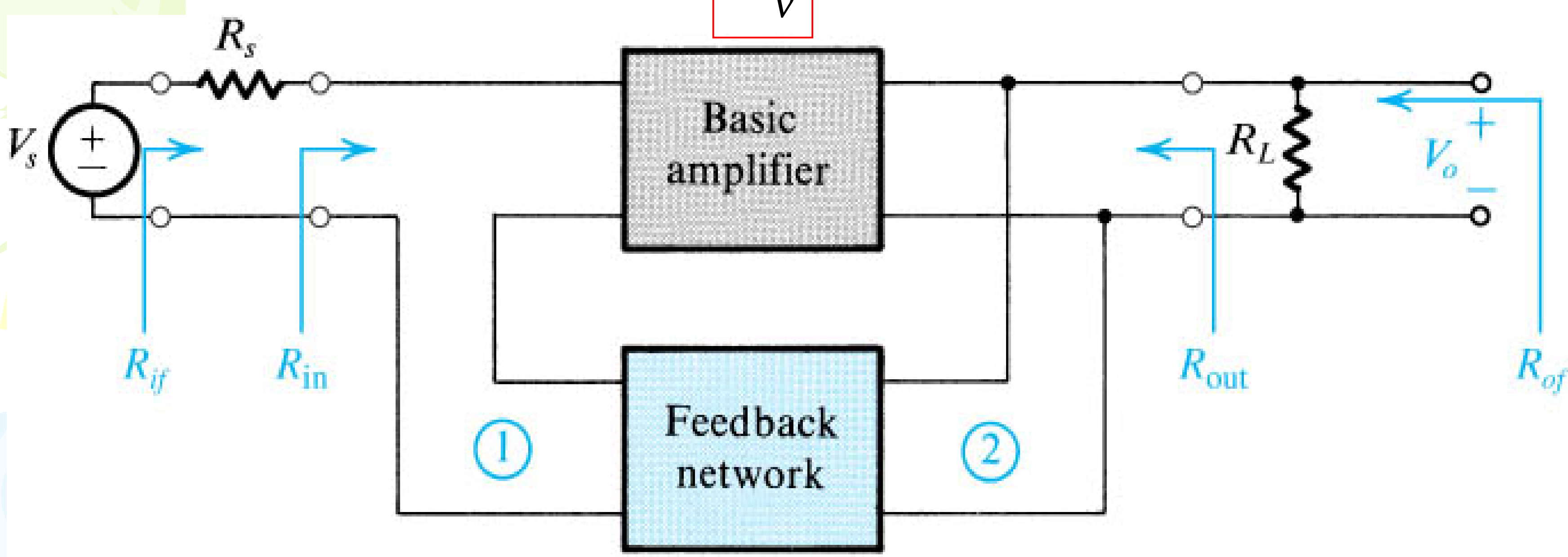
and the gain A is defined $A \equiv \dfrac{V_o}{V_i}$

(b) β is obtained from

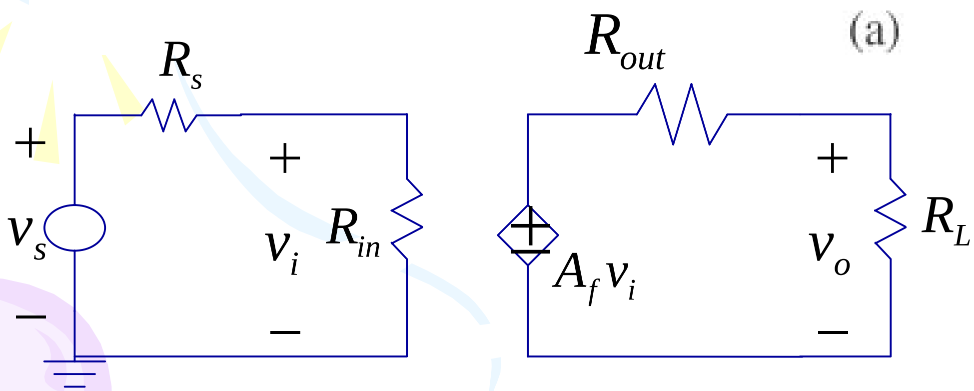


$$\beta \equiv \left.\frac{V_f}{V_o}\right|_{I_1=0}$$

$\boxed{A_v}$



(a)

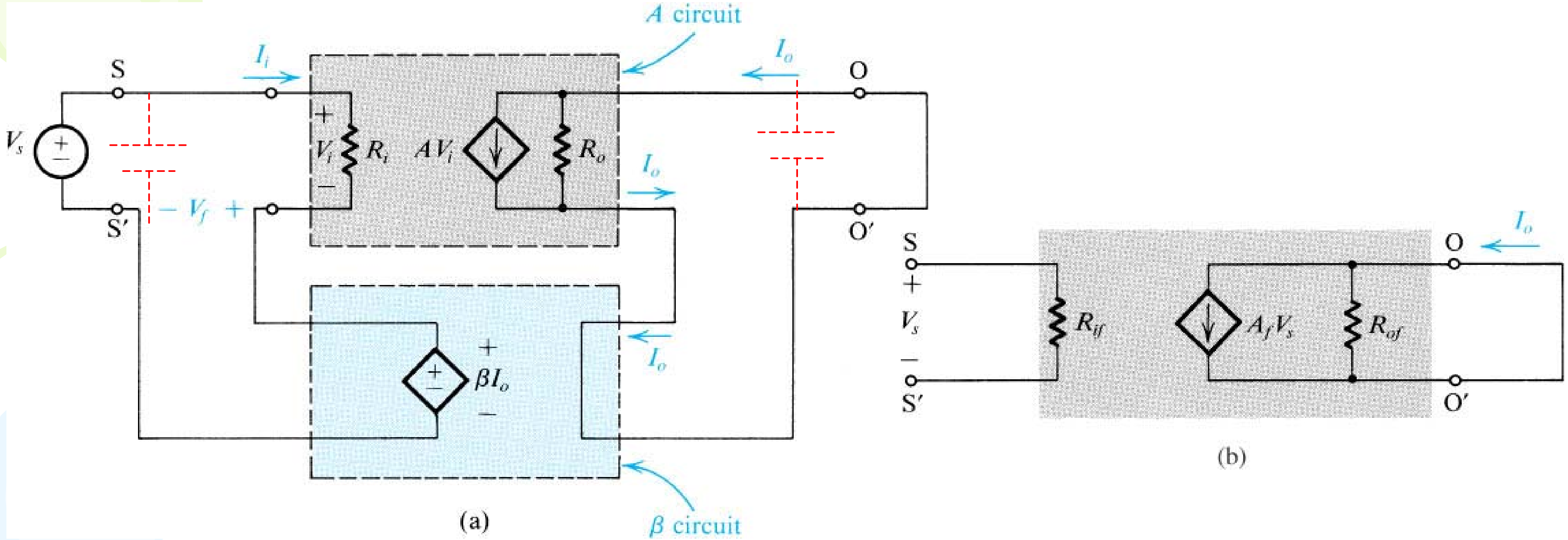


$$R_{if} = (1+\beta A)R_i = R_s + R_{in}$$

$$R_{of} = \frac{R_o}{(1+\beta A)} = R_{out} // R_L$$

Series -Shunt

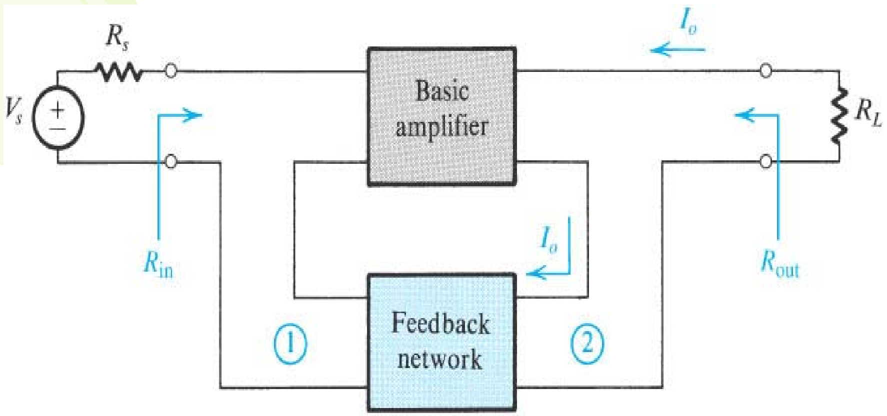
The series–series feedback amplifier



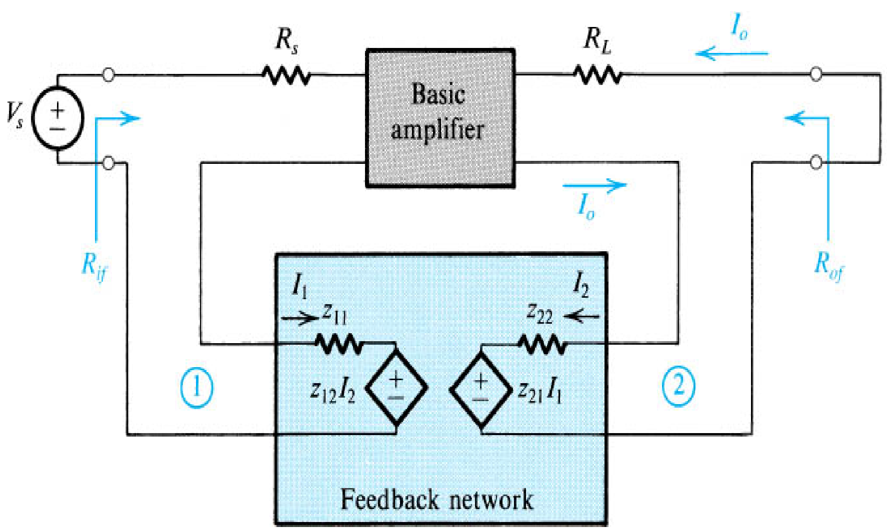
$$R_{if} = \frac{V}{I}\Big|_{V_o=0} = \frac{V_i + \beta I_o}{V_i / R_i} = \frac{V_i + \beta A v_i}{V_i / R_i} = R_i(1+\beta A)$$

$$R_{of} = \frac{V_o}{I_o}\Big|_{V_S=0} \Rightarrow V_o = (I_o - AV_i)R_o = [I_o - A(-\beta I_o)]R_o = (1+\beta A)R_o I$$

$$R_{of} = (1+\beta A)R_o$$



(a)

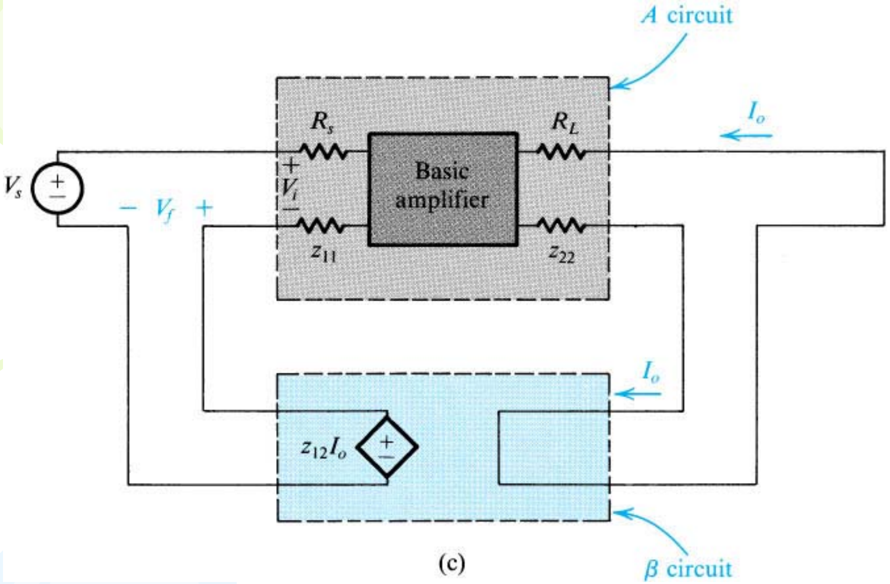


(b)

$$V_1 = z_{11}I_1 + z_{12}I_2$$

$$V_2 = z_{21}I_1 + z_{22}I_2$$

$$\begin{bmatrix} V_1 \\ V_2 \end{bmatrix} = \begin{bmatrix} z_{11} & z_{12} \\ z_{21} & z_{22} \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \end{bmatrix}$$



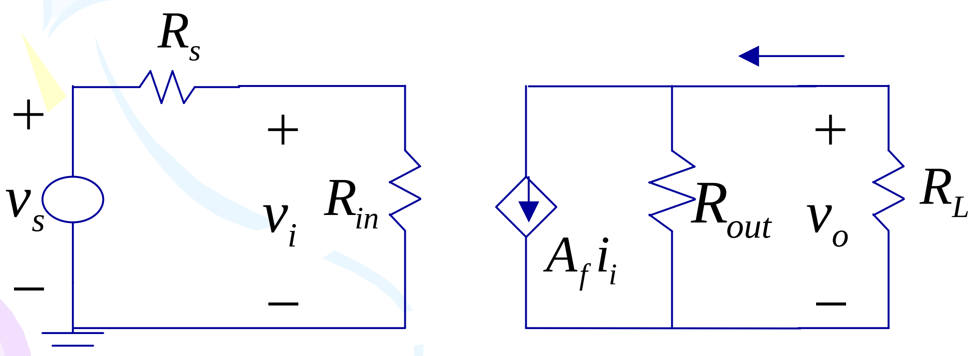
$$A = A_B \times \frac{R_i}{R_s + R_i + z_{11}} \times \frac{R_o}{R_o + R_L + z_{22}}$$

$$R_{if} = (1+\beta A)(R_s + R_i + z_{11}) = R_s + R_{in}$$

$$R_{of} = (1+\beta A)(R_L + R_o + z_{22}) = R_{out} + R_L$$

$$A_f = \frac{A}{1+\beta A}$$

Figure 8.15 *(Continued)* **(c)** A redrawing of the circuit in (b) with z_{21} neglected.

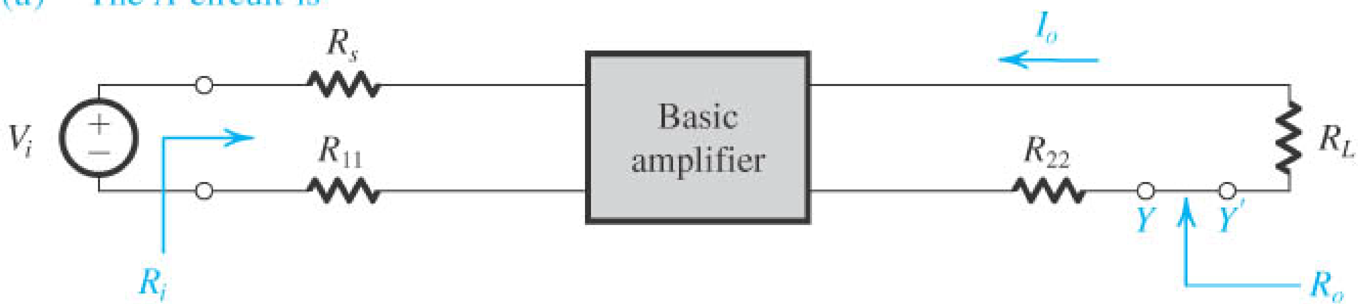


$$R_{if} = R_s + R_{in}$$

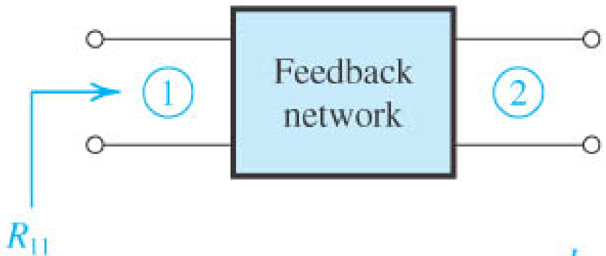
$$R_{of} = R_{out} + R_L$$

$\boxed{\text{Series -Series}}$

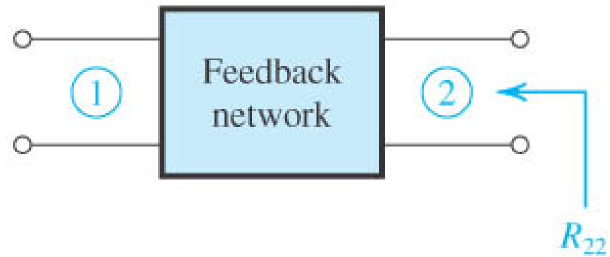
(a) The A circuit is



where R_{11} is obtained from

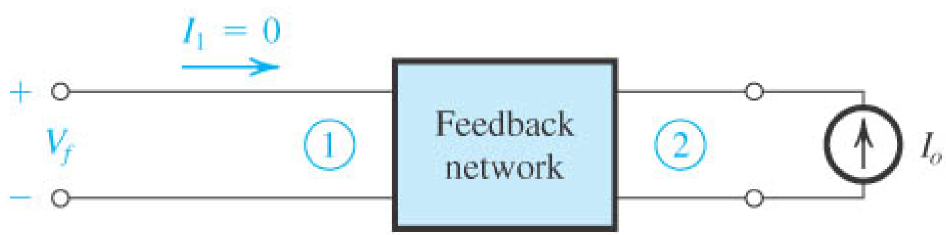


and R_{22} is obtained from



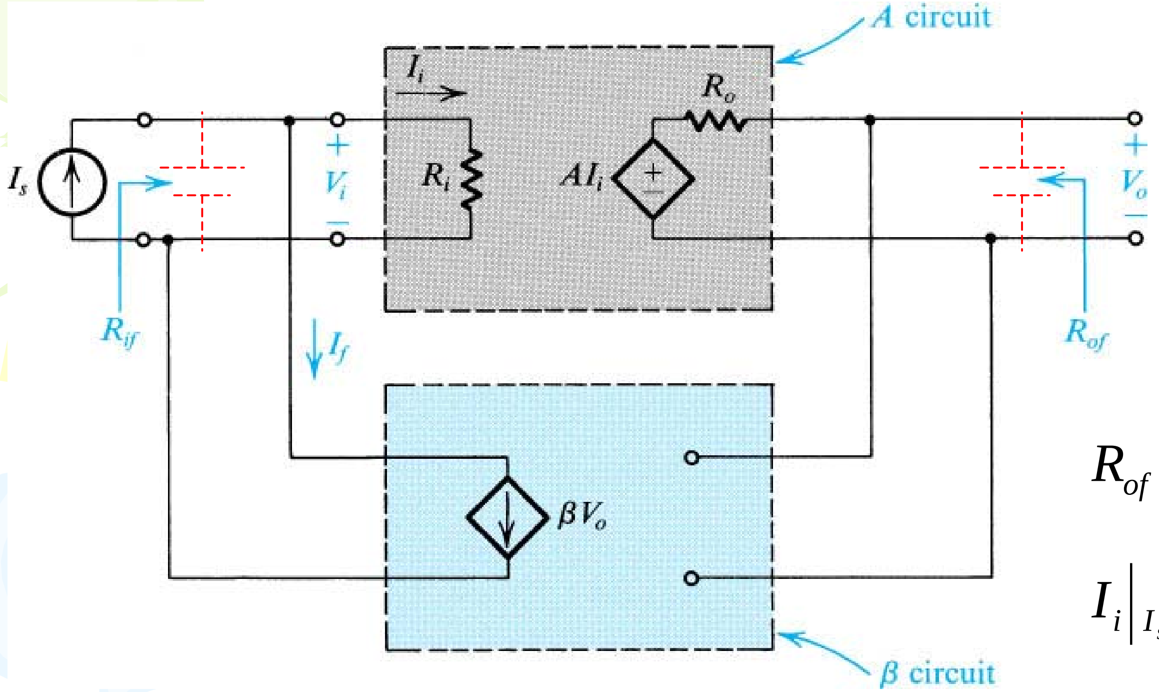
and the gain A is defined $A \equiv \dfrac{I_o}{V_i}$

(b) β is obtained from



$$\beta \equiv \left.\frac{V_f}{I_o}\right|_{I_1 = 0}$$

the shunt–shunt feedback amplifier



$$A = R_m = \frac{V_o}{I_i}$$

$$R_{if} = \frac{V_s}{I_s} = \frac{V_s}{I_i + \beta V_o} = \frac{V_s}{I_i + \beta A I_i} = \frac{I_i R_i}{I_i + \beta A I_i}$$

$$R_{if} = \frac{R_i}{1+\beta A}$$

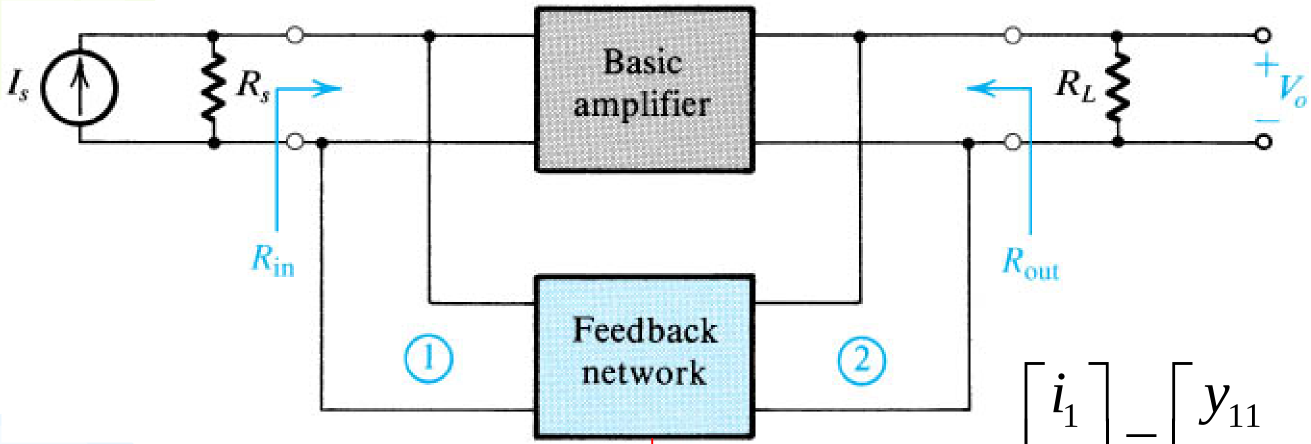
$$R_{of} = \frac{V_o}{I_o} = \frac{I_o R_o + A I_i}{I_o}$$

$$I_i \Big|_{I_s=0} = -\beta V_o = -\beta (I_o R_o + A I_i)$$

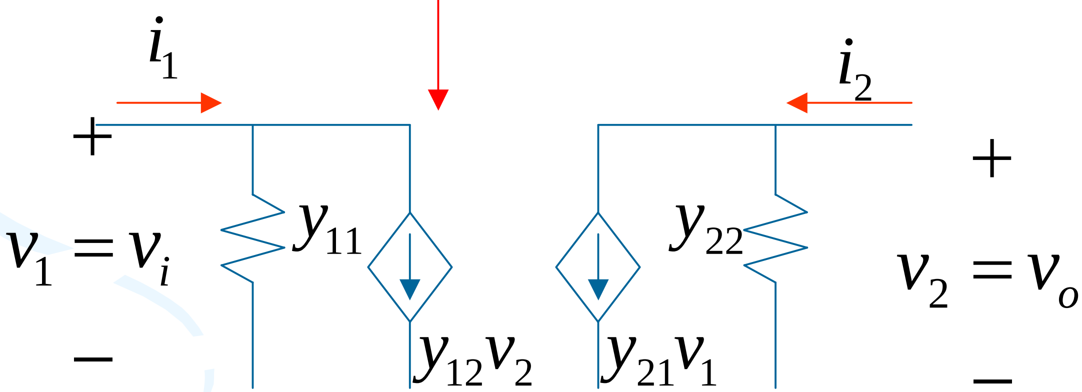
$$I_i = \frac{-\beta I_o R_o}{1+\beta A}$$

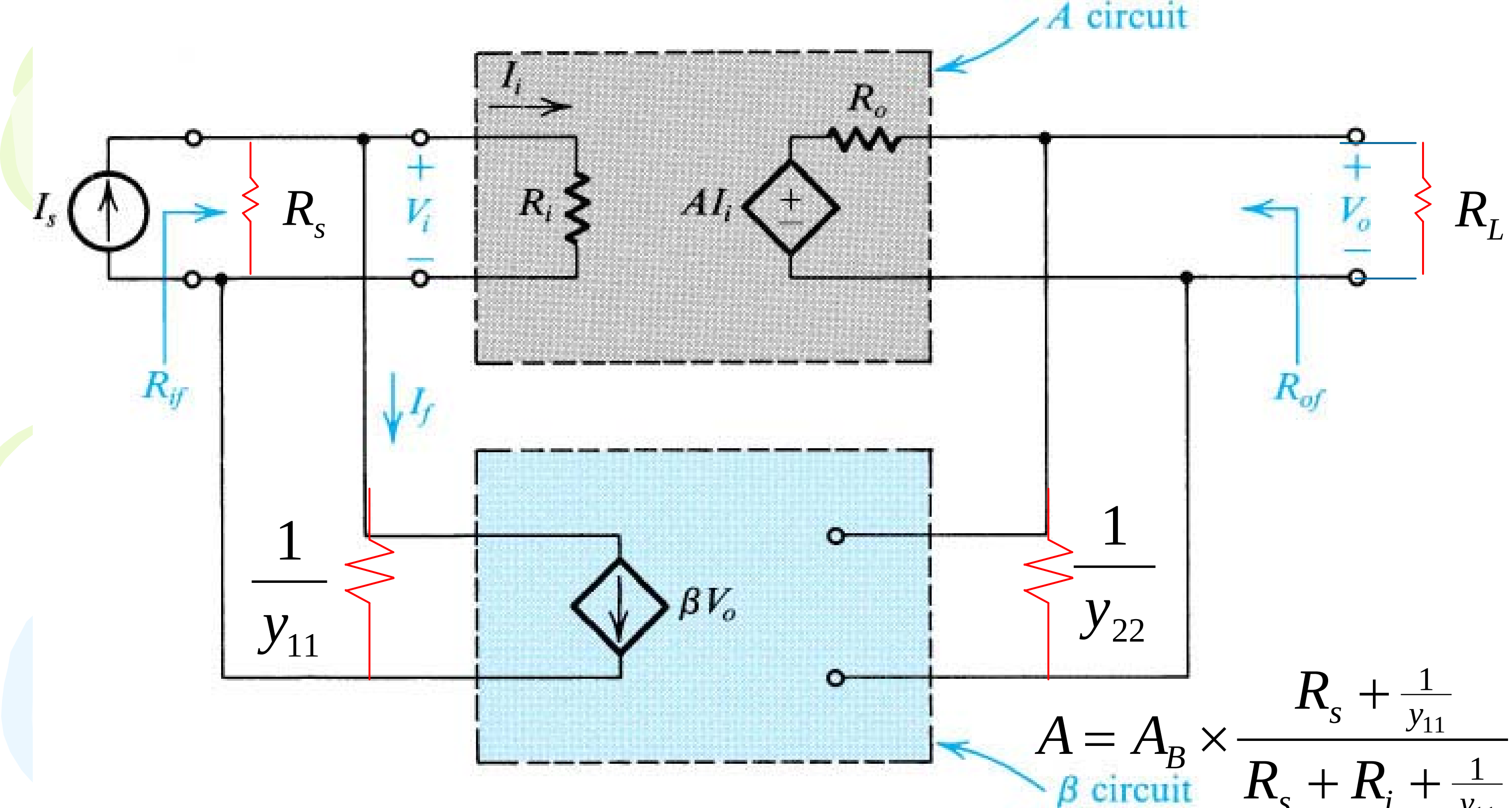
$$R_{of} = \frac{V_o}{I_o} = \frac{I_o R_o + A \dfrac{-\beta I_o R_o}{1+\beta A}}{I_o}$$

$$= R_o \left(1 + A \frac{-\beta}{1+\beta A}\right) = R_o \frac{1}{1+\beta A}$$

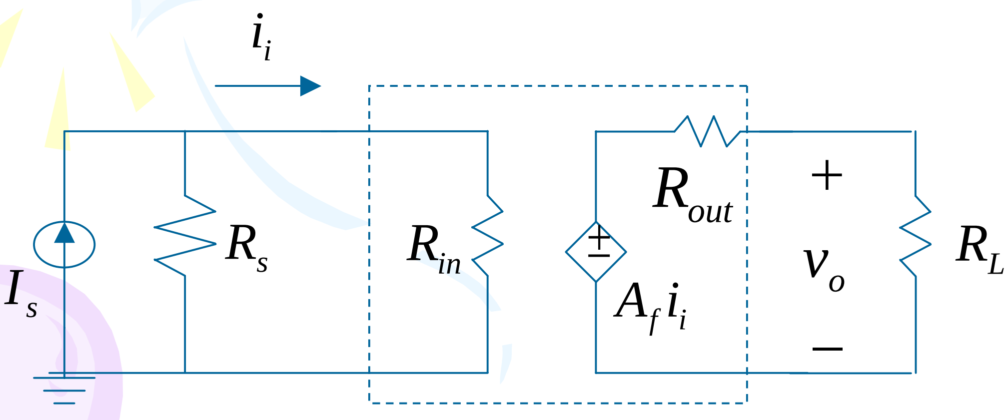


$$\begin{bmatrix} i_1 \\ i_2 \end{bmatrix} = \begin{bmatrix} y_{11} & y_{12} \\ y_{21} & y_{22} \end{bmatrix} \begin{bmatrix} v_1 \\ v_2 \end{bmatrix}$$





$$A = A_B \times \frac{R_s + \frac{1}{y_{11}}}{R_s + R_i + \frac{1}{y_{11}}} \times \frac{R_o}{R_o + (R_L // \frac{1}{y_{22}})}$$

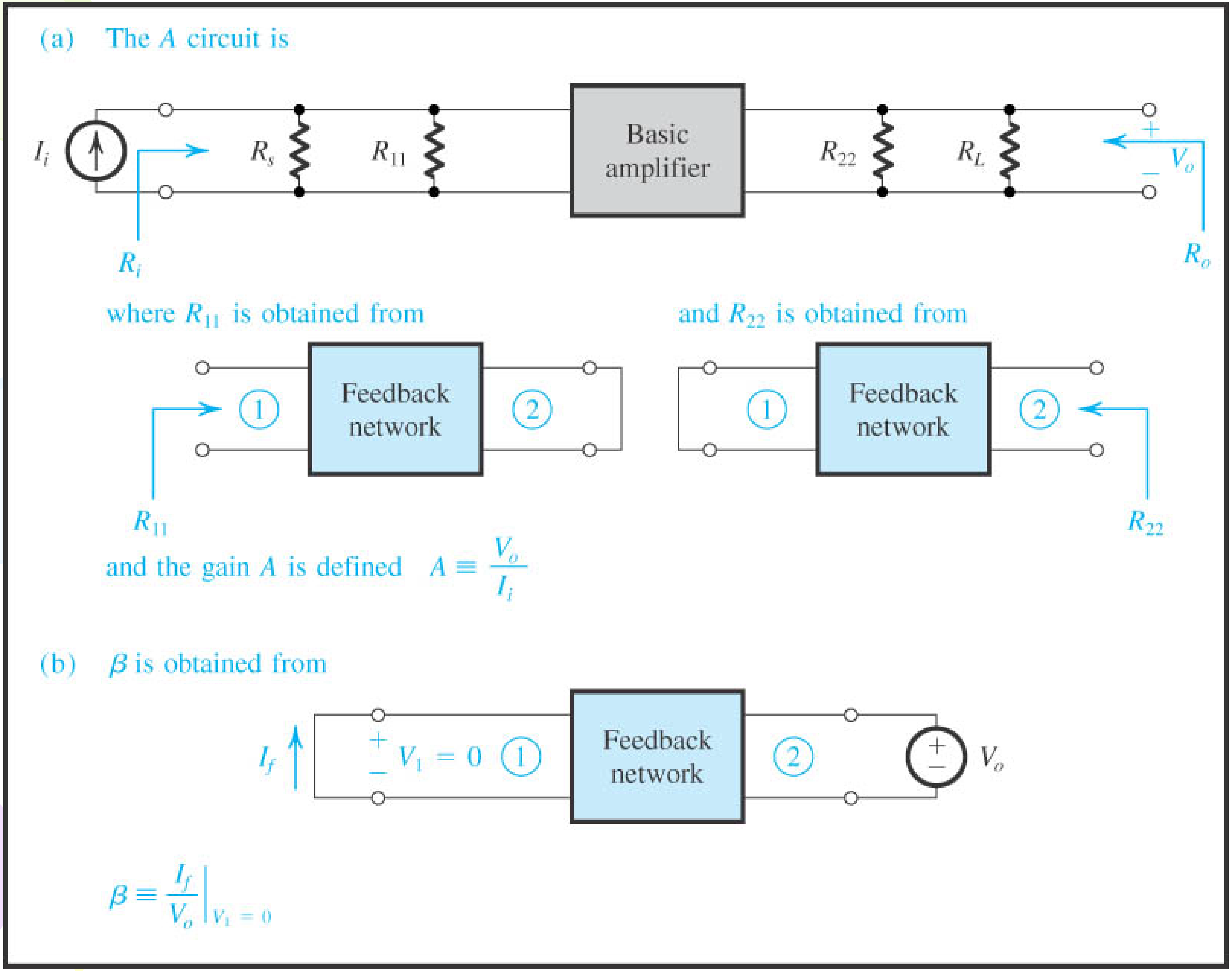


$$R_{if} = \frac{(R_s // R_i // \frac{1}{y_{11}})}{(1+\beta A)} = R_s // R_{in}$$

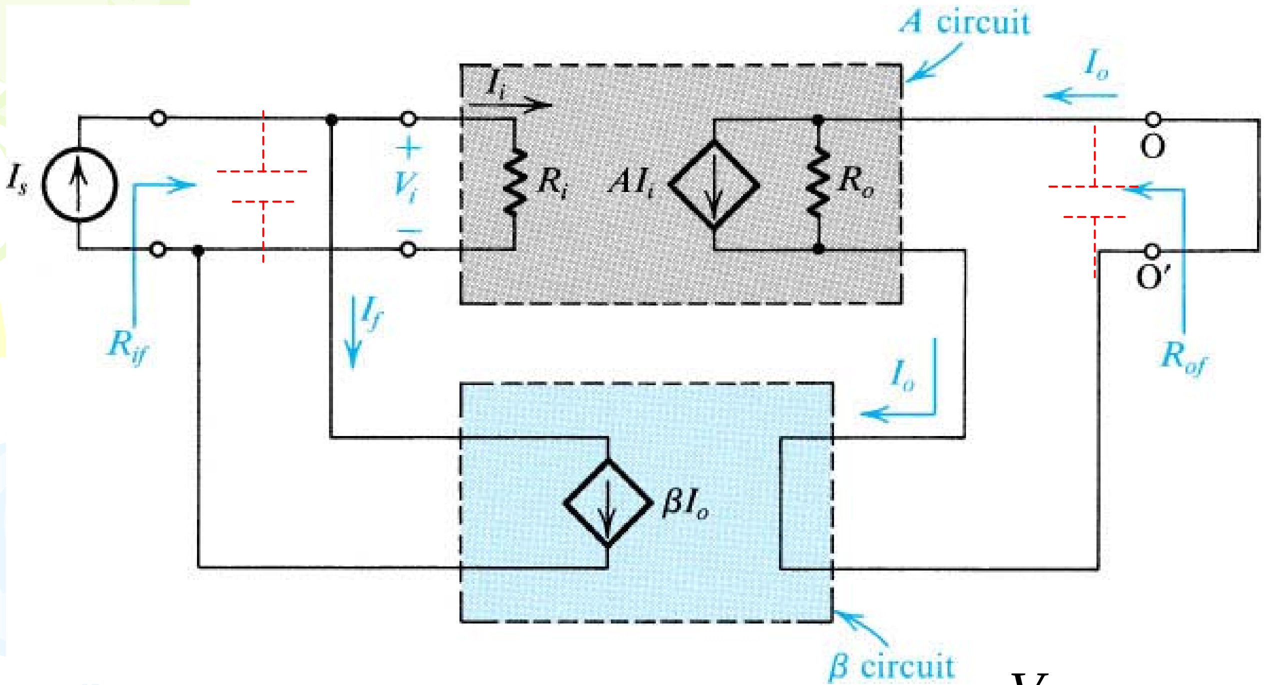
$$R_{of} = \frac{R_o // \frac{1}{y_{22}} // R_L}{(1+\beta A)} = R_{out} // R_L$$

$$A_f = \frac{A}{1+\beta A}$$

$\boxed{\text{Shunt -Shunt}}$


(a) The A circuit is
I_i
R_s
R_{11}
Basic amplifier
R_{22}
R_L
+
V_o
−
R_i
R_o
where R_{11} is obtained from
and R_{22} is obtained from
Feedback network
1
2
R_{11}
R_{22}
and the gain A is defined $A \equiv \frac{V_o}{I_i}$
(b) β is obtained from
I_f
$V_1 = 0$
V_o
$\beta \equiv \left.\frac{I_f}{V_o}\right|_{V_1 = 0}$

The shunt–series feedback amplifier



$$I_s = \frac{V_s}{R_i} + \beta I_o$$

$$I_o\Big|_{V_o=0} = AI_i \Rightarrow I_s = \frac{V_s}{R_i} + \beta AI_i = \frac{V_s}{R_i} + \beta A\frac{V_s}{R_i}$$

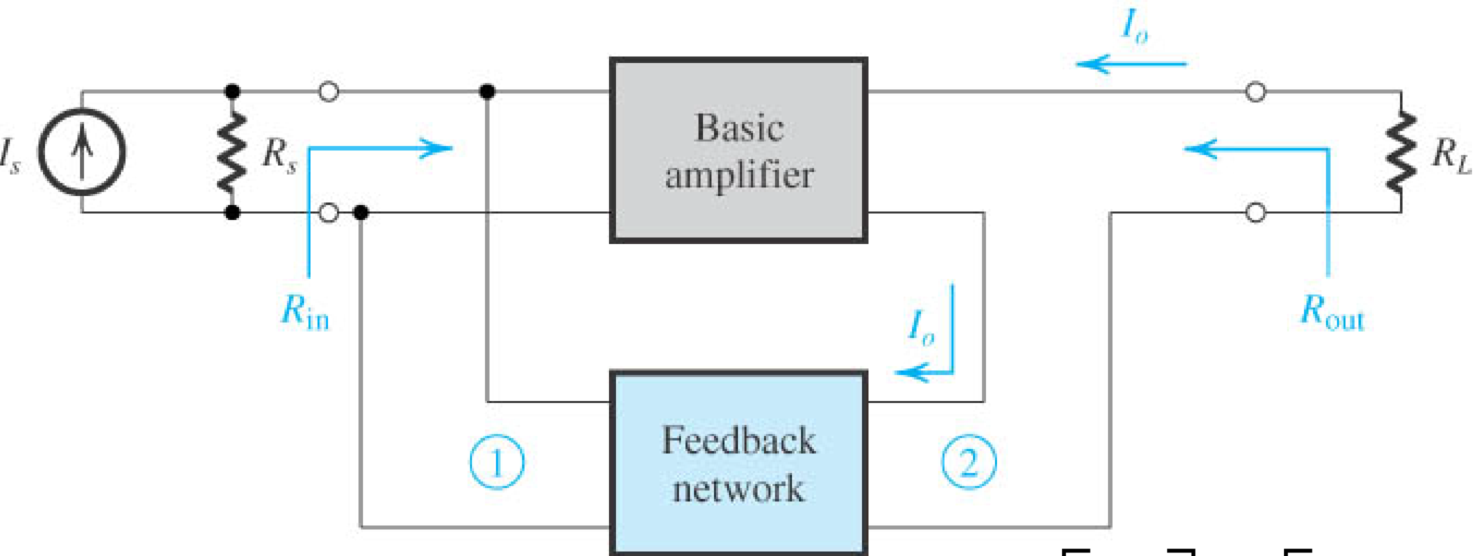
$$R_{if} = \frac{R_i}{1+\beta A}$$

$$R_{of} = \frac{V_o}{I_o}\Big|_{I_s=0}$$

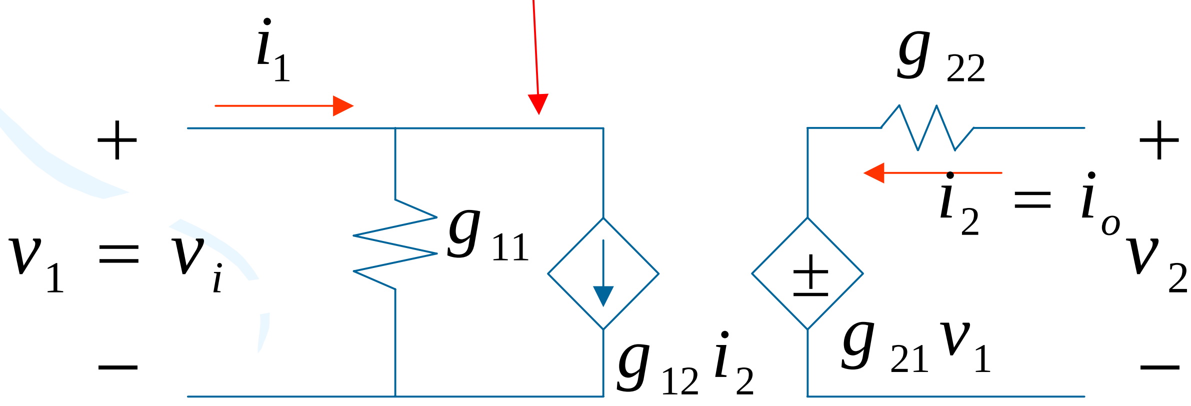
$$\Rightarrow V_o = (I_o - AI_i)R_o = [I_o - A(-\beta I_o)]R_o$$

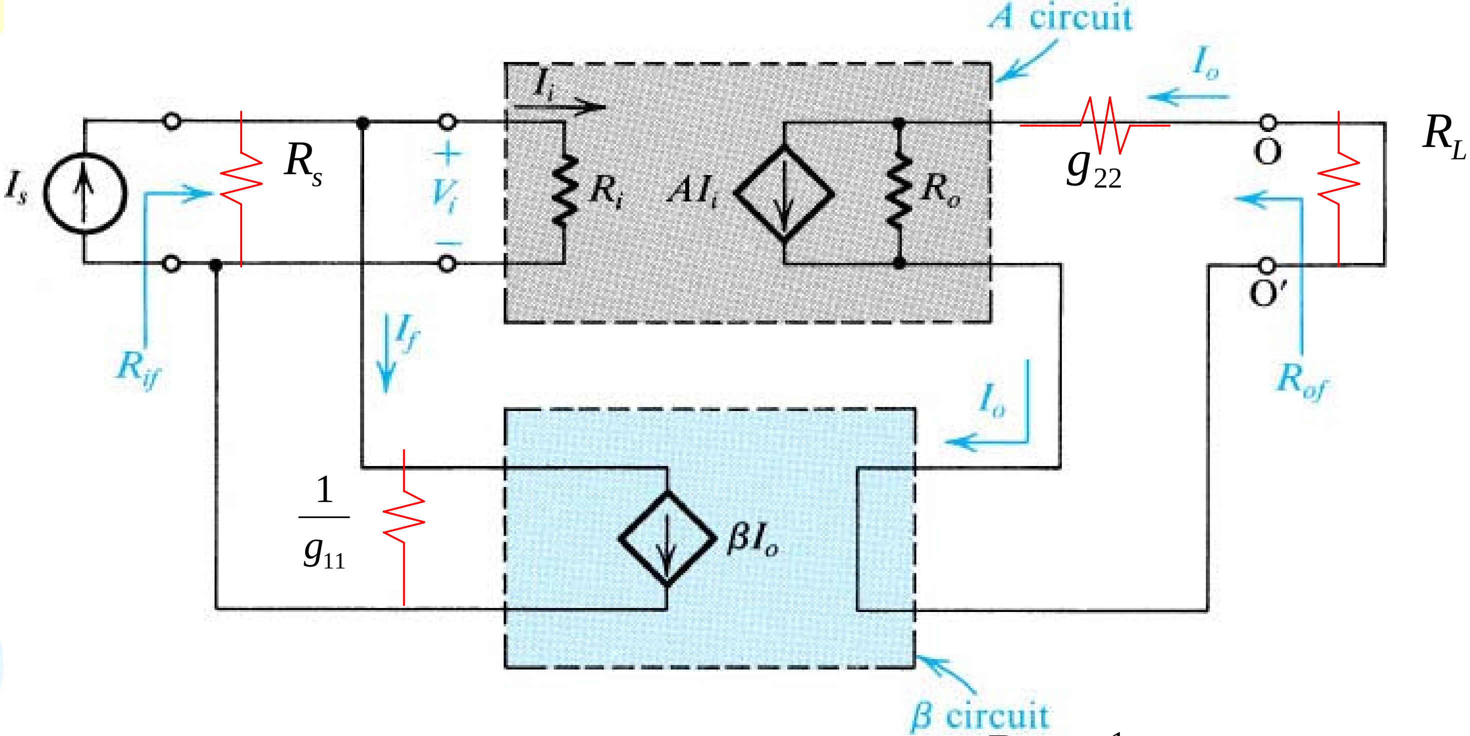
$$= (1+\beta A)R_o I_o$$

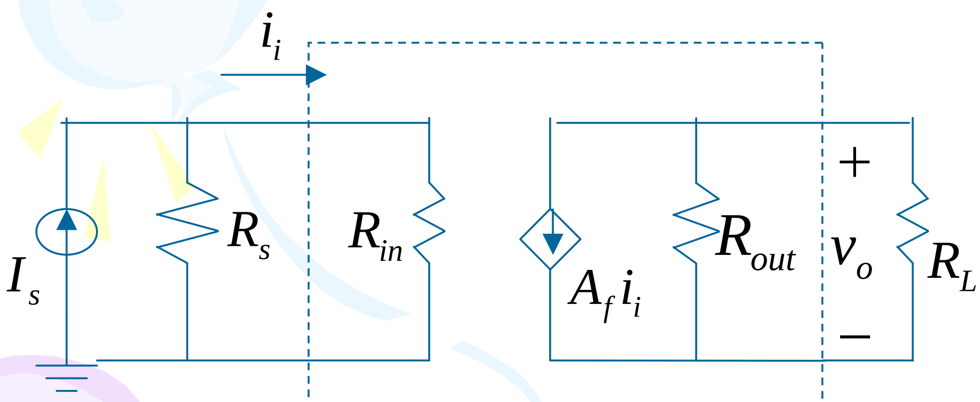
$$R_{of} = \frac{V_o}{I_o}\Big|_{I_s=0} = (1+\beta A)R_o$$



$$\begin{bmatrix} i_1 \\ v_2 \end{bmatrix} = \begin{bmatrix} g_{11} & g_{12} \\ g_{21} & g_{22} \end{bmatrix} \begin{bmatrix} v_1 \\ i_2 \end{bmatrix}$$







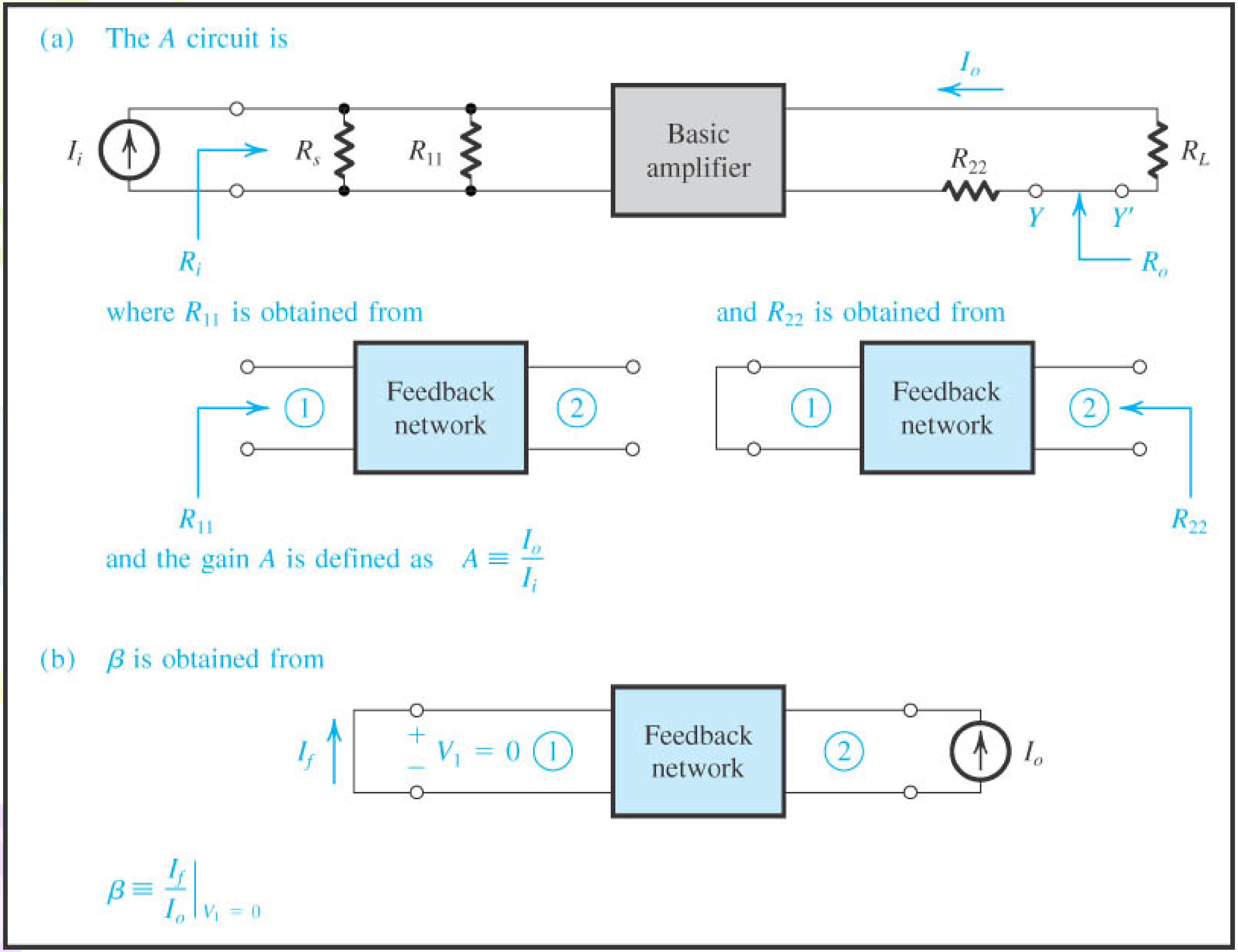
$$A = A_B \times \frac{R_S + \frac{1}{g_{11}}}{R_s + R_i + \frac{1}{g_{11}}} \times \frac{R_o}{R_o + R_L + g_{22}}$$

$$R_{if} = \frac{(R_s // R_i // \frac{1}{y_{11}})}{(1+\beta A)} = R_s // R_{in}$$

$$R_{of} = (1+\beta A)(R_o + g_{22} + R_L) = R_{out} + R_L$$

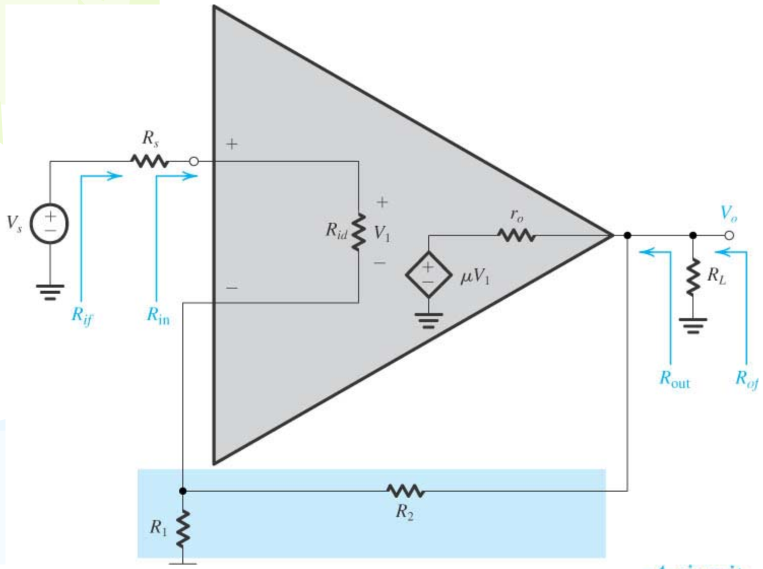
$$A_f = \frac{A}{1+\beta A}$$

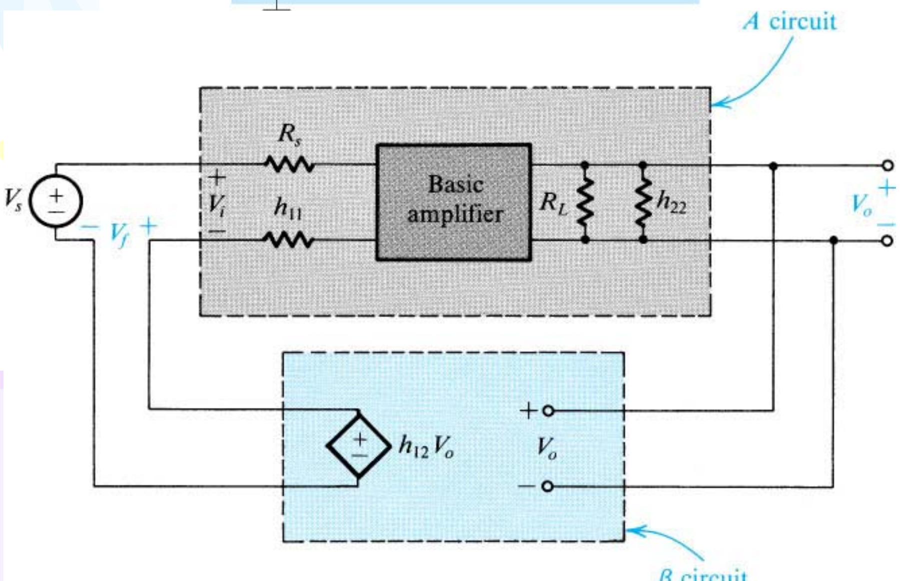
Shunt -Series


(a) The A circuit is
I_o
I_i
R_s
R_{11}
Basic amplifier
R_{22}
R_L
Y
Y'
R_i
R_o
where R_{11} is obtained from
Feedback network
1
2
R_{11}
and R_{22} is obtained from
Feedback network
1
2
R_{22}
and the gain A is defined as $A \equiv \frac{I_o}{I_i}$
(b) β is obtained from
I_f
$V_1 = 0$
1
Feedback network
2
I_o
$\beta \equiv \left.\frac{I_f}{I_o}\right|_{V_1 = 0}$

Type	Amplifier	Feedback parameter	$A_f = \dfrac{A}{1+\beta A}$	R_{if}	R_{of}
Series-Shunt (voltage-voltage)	$A_v = \dfrac{v_o}{v_i}$	$\begin{bmatrix} v_1 \\ i_2 \end{bmatrix} = h$	$A_f = \dfrac{A_v}{1+h_{12}A_v}$	$R_{if} = (1+\beta A)R_i$	$R_{if} = \dfrac{R_o}{1+\beta A}$
Series-Series (voltage-current)	$G_m = \dfrac{i_o}{v_i}$	$\begin{bmatrix} v_1 \\ v_2 \end{bmatrix} = z$	$G_{mf} = \dfrac{G_m}{1+z_{12}G_m}$	$R_{if} = R_i(1+\beta A)$	$R_{of} = R_o(1+\beta A)$
Shunt-Shunt (current-voltage)	$R_m = \dfrac{v_o}{i_i}$	$\begin{bmatrix} i_1 \\ i_2 \end{bmatrix} = y$	$R_{mf} = \dfrac{R_m}{1+y_{12}R_m}$	$R_{if} = \dfrac{R_i}{(1+\beta A)}$	$R_{of} = \dfrac{R_o}{(1+\beta A)}$
shunt-series (current-current)	$A_I = \dfrac{i_o}{i_i}$	$\begin{bmatrix} i_1 \\ v_2 \end{bmatrix} = g$	$A_{If} = \dfrac{A_I}{1+g_{12}A_I}$	$R_{if} = \dfrac{R_i}{1+\beta A}$	$R_{of} = (1+\beta A)R_o$

Example 8.1





(c)

Step 0 : Series-shunt feedback amplifier

Amplifier → Voltage amplifier

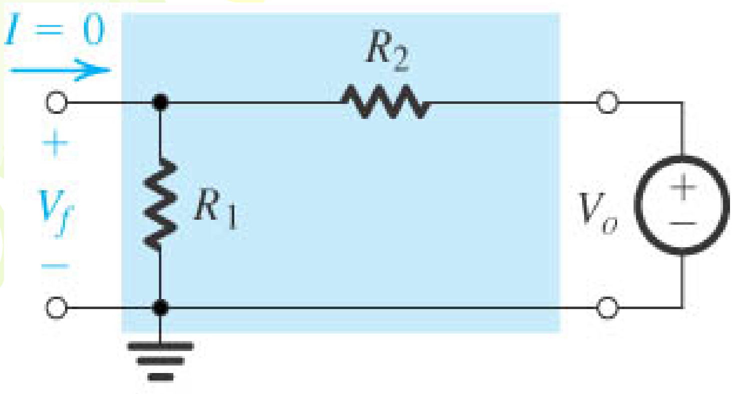
Feedback → h parameters

Step 1 : Amplifier analysis

$$R_i = R_{id}$$

$$R_o = r_o$$

$$A = \frac{V_o}{V_i} = \underbrace{\boxed{\mu}}_{A_B} \frac{(R_L // h_{22})}{(R_L // h_{22}) + r_o} \frac{R_{id}}{R_{id} + R_s + h_{11}}$$



(c)

Step 2 : Feedback network analysis

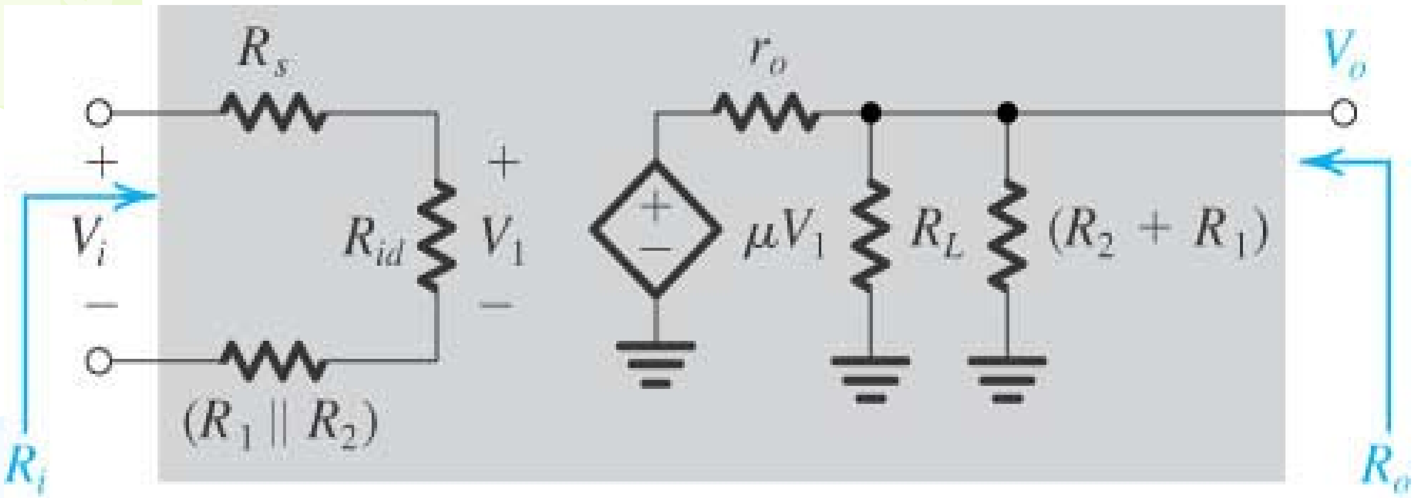
$$V_1 = h_{11} I_1 + h_{12} V_2$$
$$I_2 = h_{21} I_1 + h_{22} V_2$$

$$h_{11} = \frac{V_1}{I_1}\Big|_{V_2=0} = R_1 // R_2$$

$$h_{22} = \frac{I_1}{V_2}\Big|_{I_1=0} = R_1 + R_2$$

$$h_{12} = \frac{V_1}{V_2}\Big|_{I_1=0} = \frac{R_1}{R_1 + R_2} = \beta$$

Step 3 : Amp+Feedback analysis



(b)

$$R_{if} = (1+\beta A)(R_s + R_i + h_{11}) = (1+\beta A)(R_s + R_{id} + (R_1 // R_2)) = R_s + R_{in}$$

$$\boxed{R_{in} = R_s - R_{if}}$$

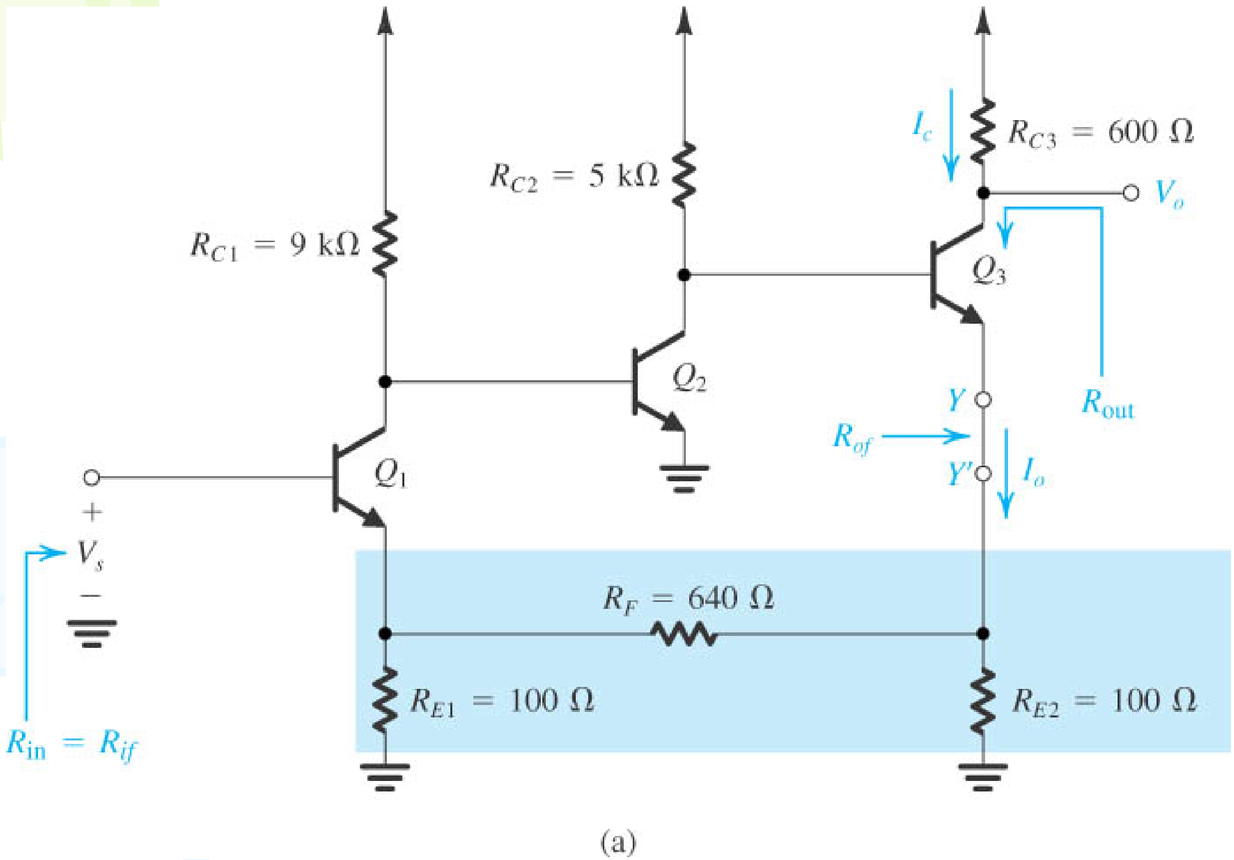
$$R_{of} = \frac{R_o // \frac{1}{h_{22}} // R_L}{(1+\beta A)} = \frac{r_o //(R_1 + R_2) // R_L}{(1+\beta A)} = R_{out} // R_L$$

$$R_{out} \Rightarrow find$$

$$A_f = \frac{A}{1+\beta A}$$

Feedback AMP

Example 8.2



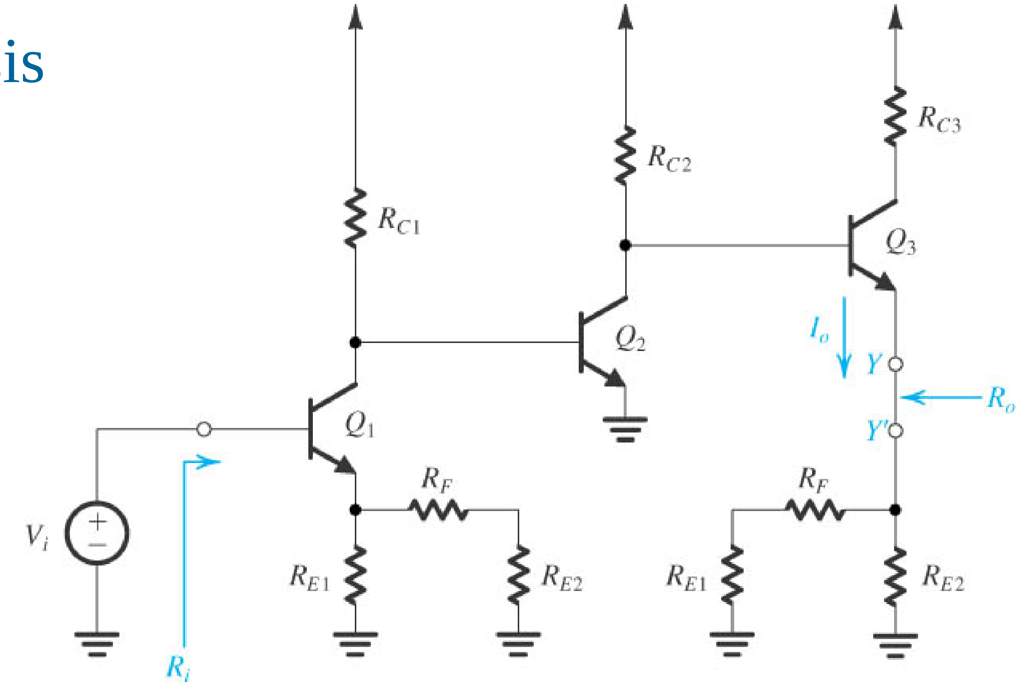
(a)

Step 0 : Series-series feedback amplifier

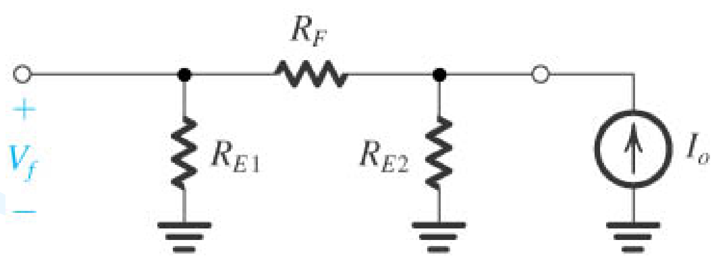
Amplifier → Transconductance amplifier

Feedback → z parameters

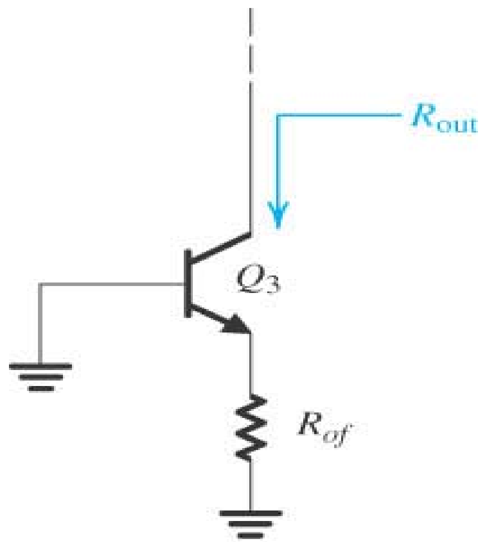
Step 1 : Amplifier analysis



(b)



(c)



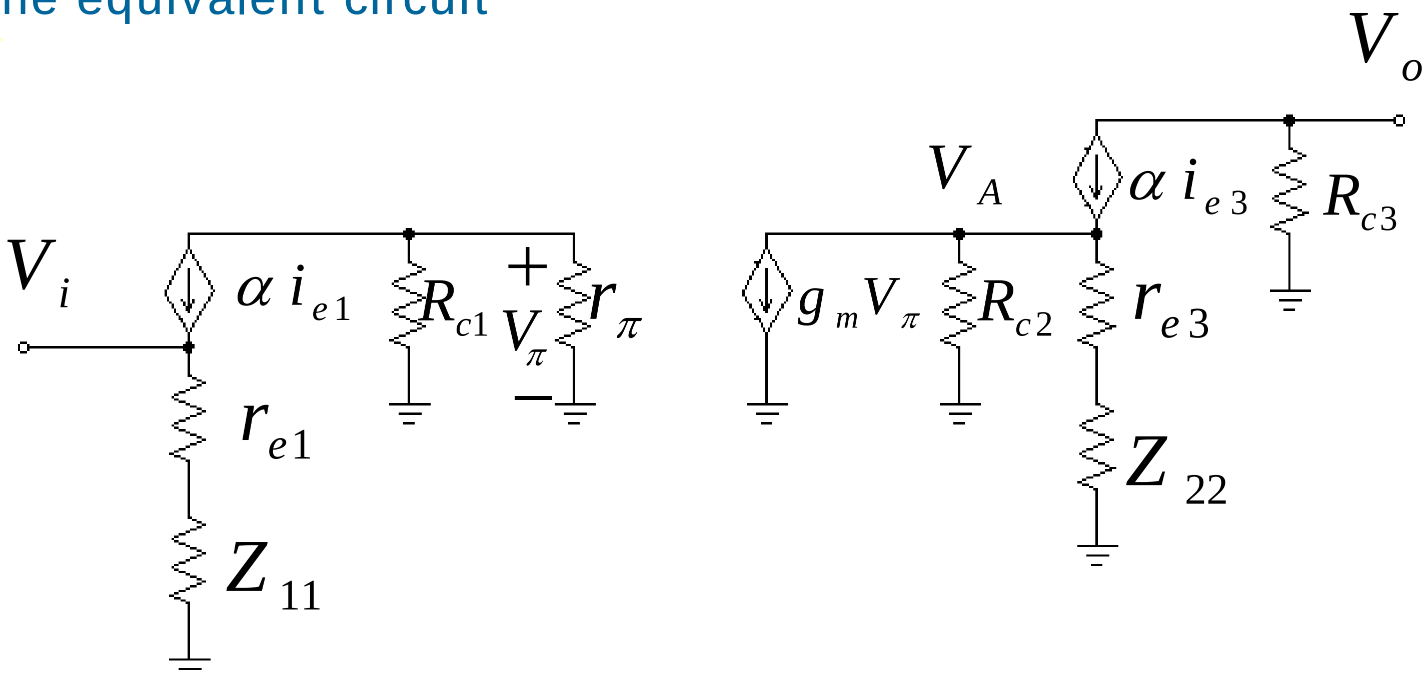
(d)

Step 2 : Analysis feedback Amp

$$Z_{11} = R_1 //(R_2 + R_3)$$

$$Z_{22} = R_3 //(R_1 + R_2)$$

The equivalent circuit



Step 3 : Amp+Feedback analysis

$$V_i = i_{e1}(r_{e1} + Z_{11})$$

$$V_A = -g_m V_\pi [R_{c2} //(1 + hfe)(r_{e3} + Z_{22})]$$

$$I_o = \frac{V_A}{r_{e2} + Z_{22}}$$

$$-\alpha i_{e1} = \frac{V_\pi}{R_{c1} // r_\pi} \Rightarrow A = \frac{I_o}{V_i}$$

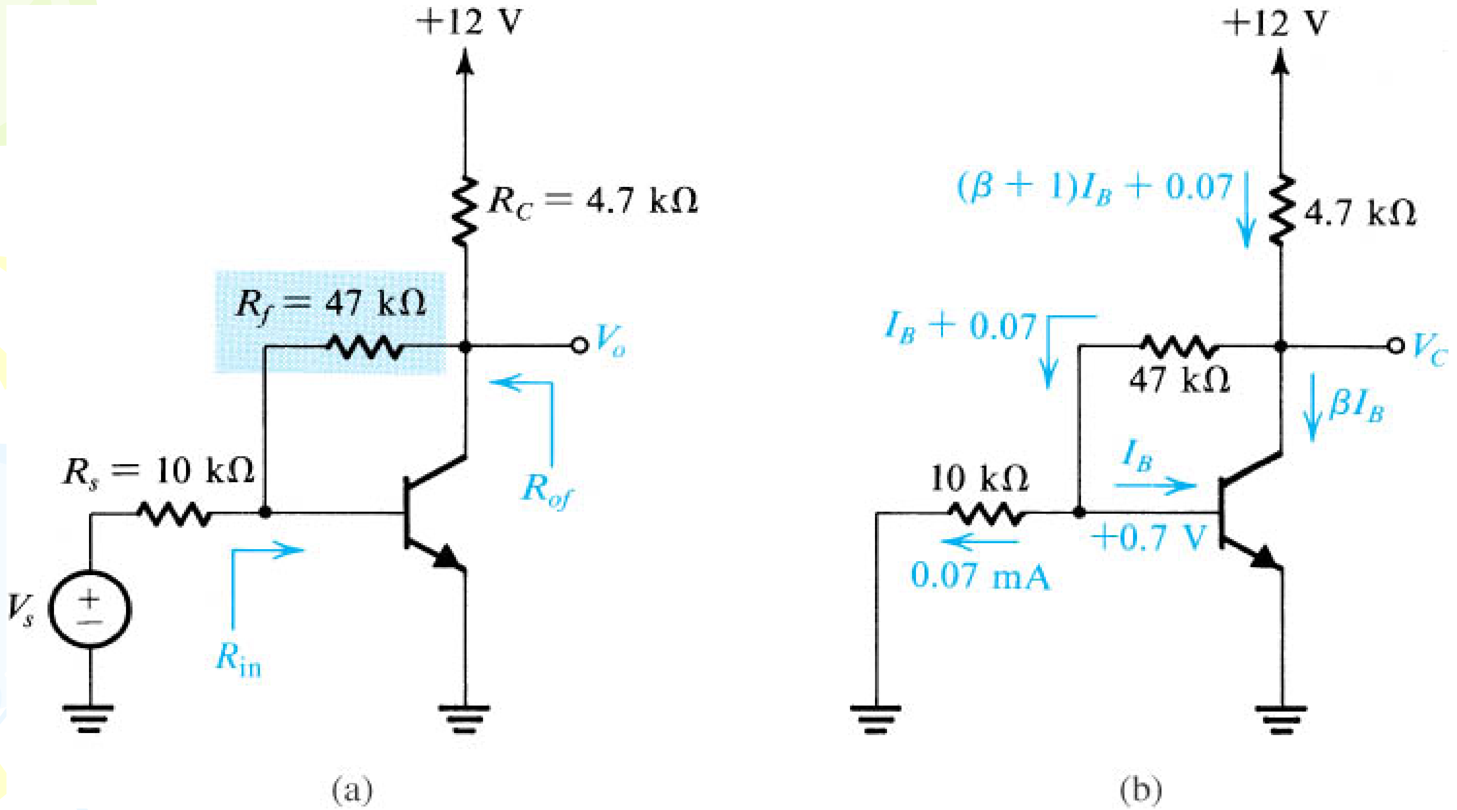
$$R_i' = (r_{e1} + Z_{11})(1 + hfe)$$

$$R_o' = r_{e3} + Z_{22} + \frac{R_{c2}}{1 + hfe}$$

$$R_{if} = (1 + \beta A')R_i'$$

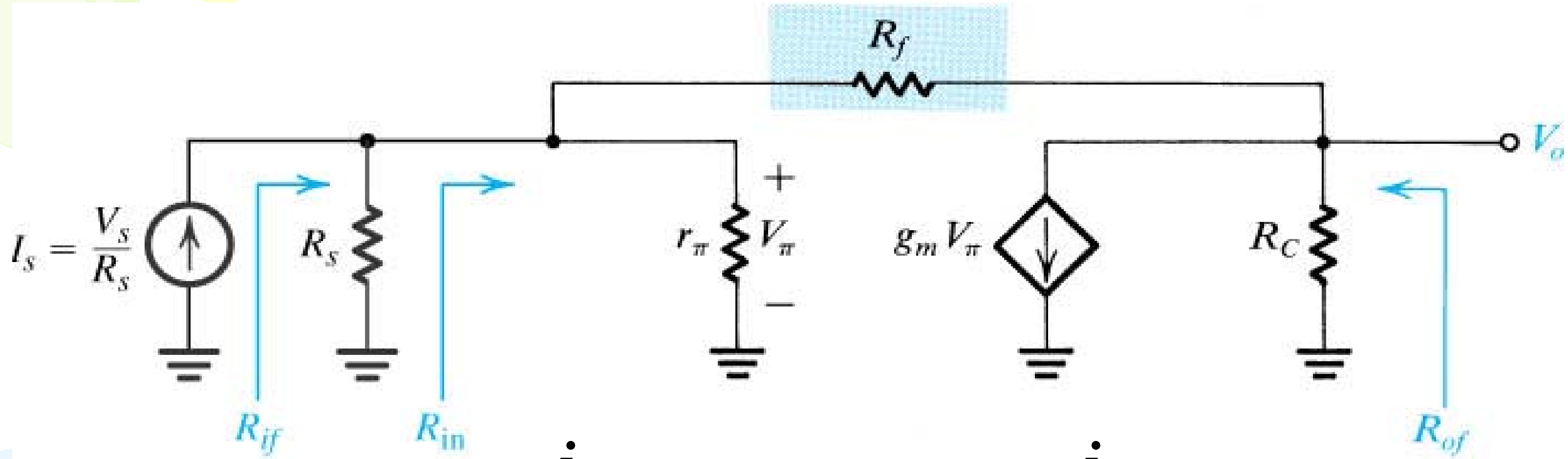
$$R_{of} = (1 + \beta A')R_o'$$

Example 8.3



Shunt-shunt: R_m amplifier + y parameter

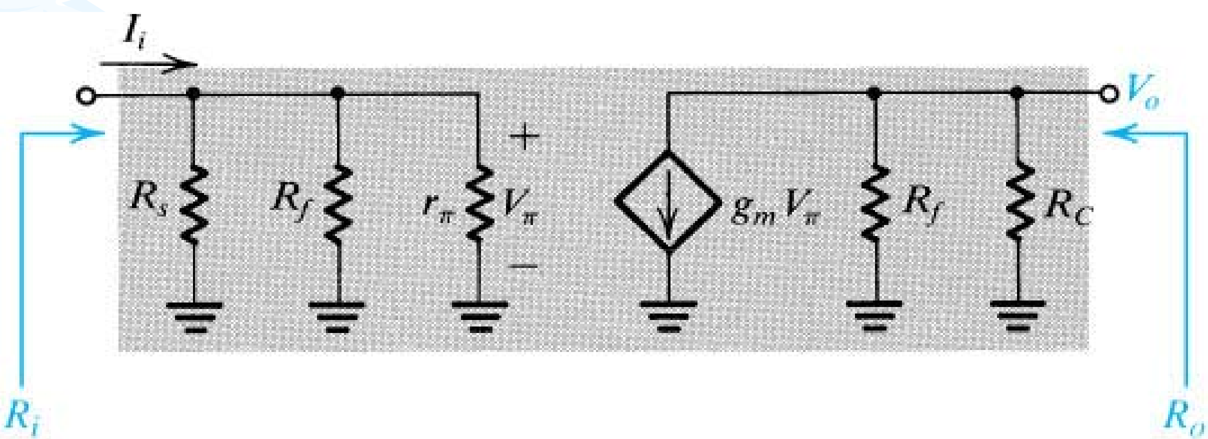
$$\begin{bmatrix} i_1 \\ i_2 \end{bmatrix} = \begin{bmatrix} y_{11} & y_{12} \\ y_{21} & y_{22} \end{bmatrix} \begin{bmatrix} v_1 \\ v_2 \end{bmatrix}$$



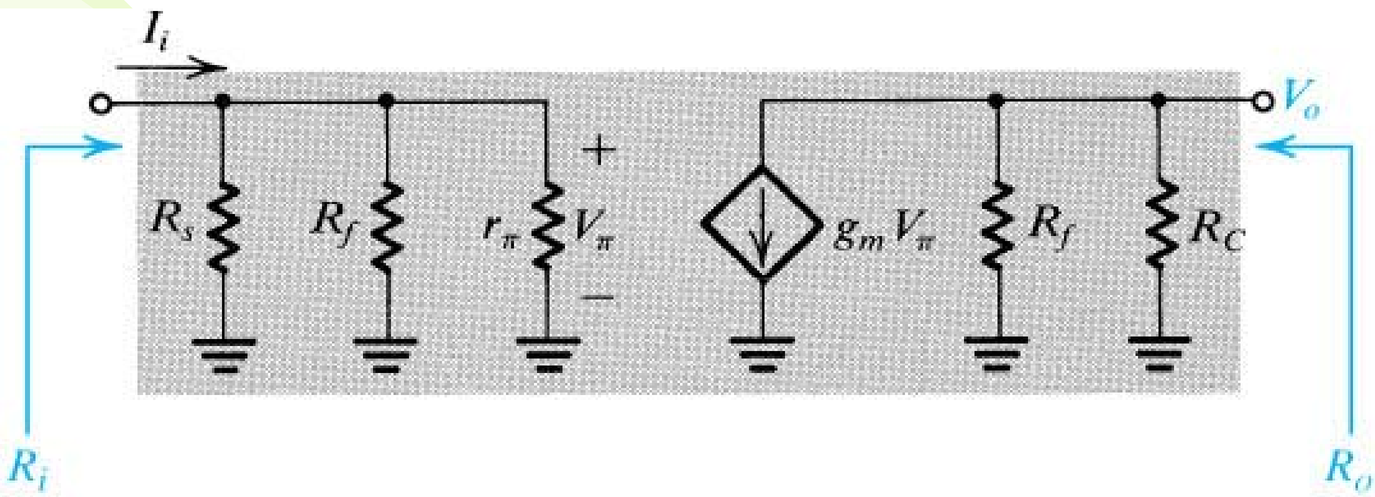
$$y_{11} = \left.\frac{i_1}{v_1}\right|_{v_2=0}$$

(c)

$$y_{22} = \left.\frac{i_2}{v_2}\right|_{v_1=0}$$



(d)



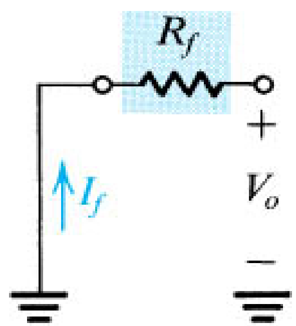
(d)

$$R_m = \frac{v_o}{i_i} = \frac{-g_m v_\pi (R_f // R_c)}{v_\pi / (R_f // R_s // r_\pi)} = -358.7k\Omega$$

$$R_i = R_f // R_s // r_\pi = 1.4k$$

$$R_o = R_f // R_c = 4.27k$$

$$\beta = y_{12} = \frac{i_f}{v_o}\bigg|_{v_s=0} = -\frac{1}{R_f}$$



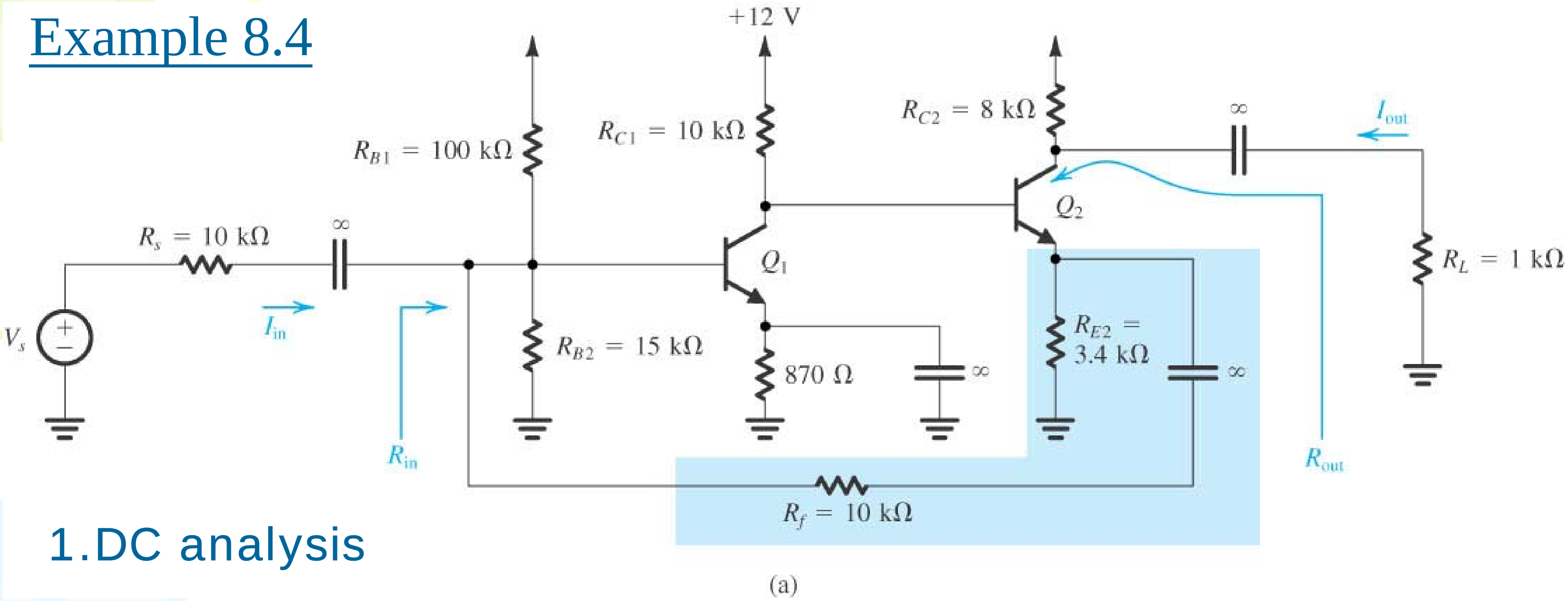
(e)

$$A_f \equiv \frac{v_o}{i_s} = R_{mf} = \frac{R_m}{1+y_{12}R_m} = -41.6k$$

$$R_{if} = \frac{R_i}{1+y_{12}R_m} = 162.2 = R_s // R_{in}$$

$$R_{of} = \frac{R_o}{1+y_{12}R_m} = 495$$

Example 8.4



1.DC analysis

(a)

$$\frac{15k}{15k+100k}\times 12V = (100k // 15k)I_{B1} + 0.7 + (1+\beta)I_{B1}\times 0.87$$

$$I_{B1} = 0.0087mA$$

$$I_{C1} = 0.87mA$$

$$V_{C1} = 12 - 0.87\times 10k = 3.3V$$

$$I_{E2} = \frac{3.3-0.7}{3.4k} = 0.765mA$$

$$g_{m1} = \frac{I_{C1}}{V_T} = 0.0344$$

$$r_{\pi 1} = \frac{V_T}{I_{B1}} = 2.9k$$

$$r_{o1} = \frac{75}{I_{C1}}$$

$$g_{m2} = \frac{I_{C2}}{V_T} = 0.030$$

$$r_{\pi 2} = \frac{V_T}{I_{B2}} \approx r_{\pi 1}$$

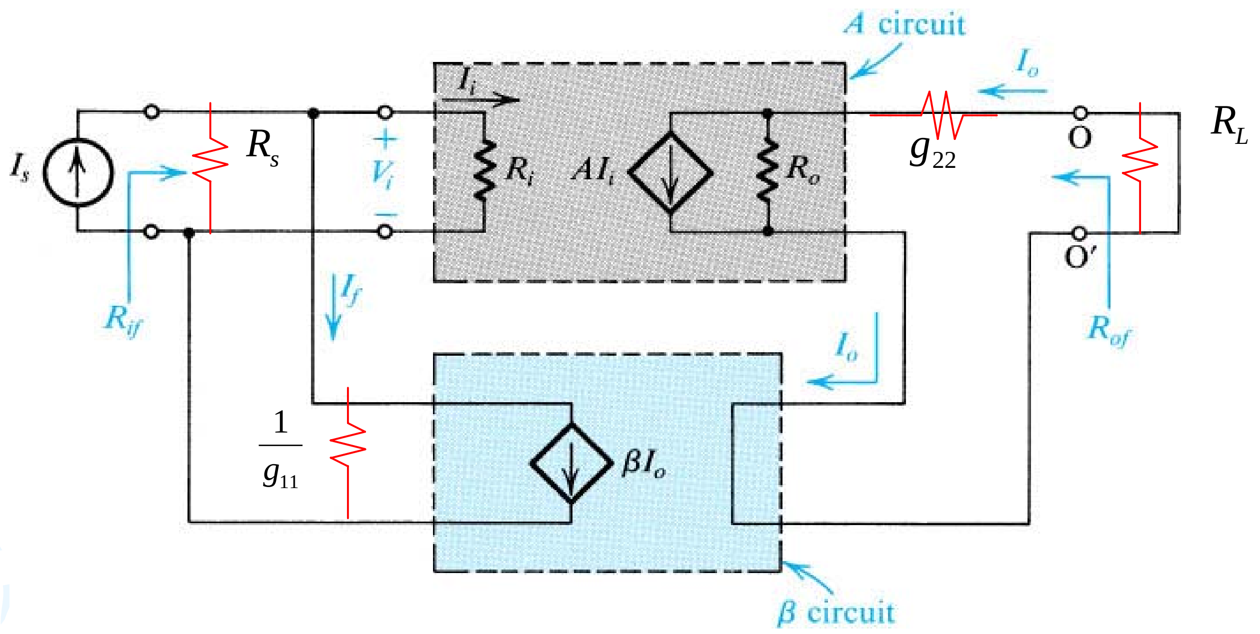
$$r_{o2} = \frac{75}{I_{C2}}$$

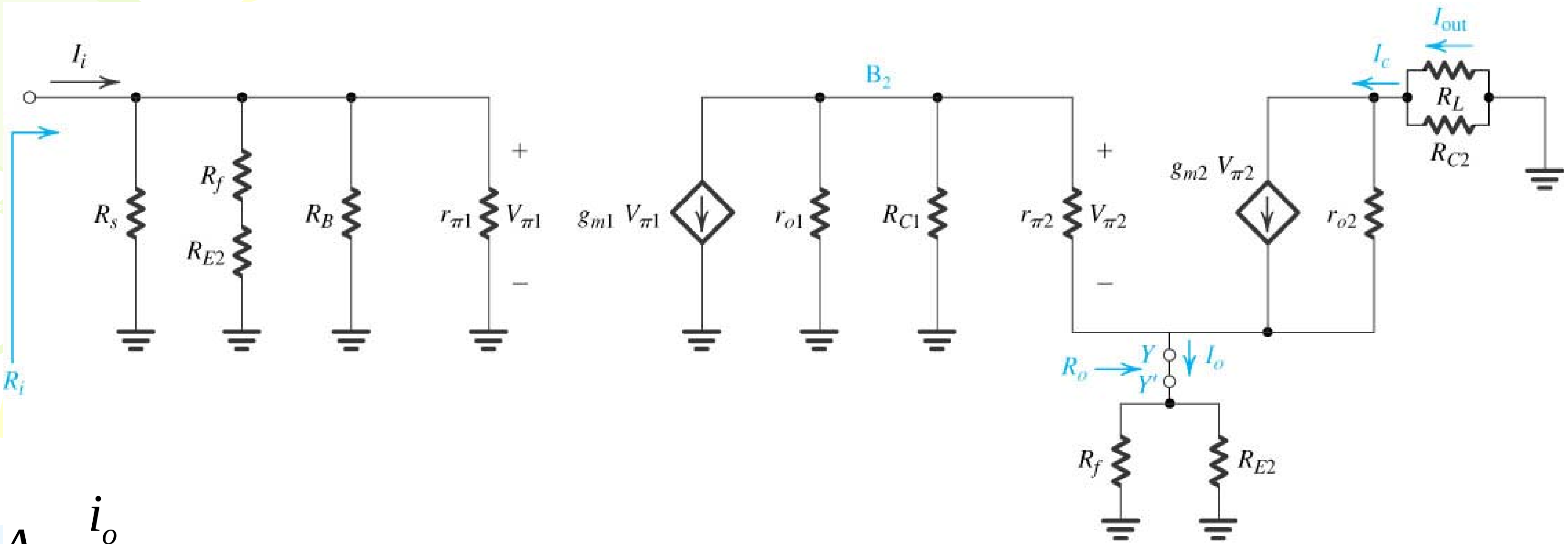
Shunt-series
current Mixing – current sampling
Amplifier: Current Amplifier
Feedback network: hybrid parameters

$$\begin{bmatrix} i_1 \\ v_2 \end{bmatrix} = \begin{bmatrix} g_{11} & g_{12} \\ g_{21} & g_{22} \end{bmatrix} \begin{bmatrix} v_1 \\ i_2 \end{bmatrix}$$

$$g_{11} = \left.\frac{i_1}{v_1}\right|_{i_2=0}$$

$$g_{22} = \left.\frac{v_2}{i_2}\right|_{v_1=0}$$



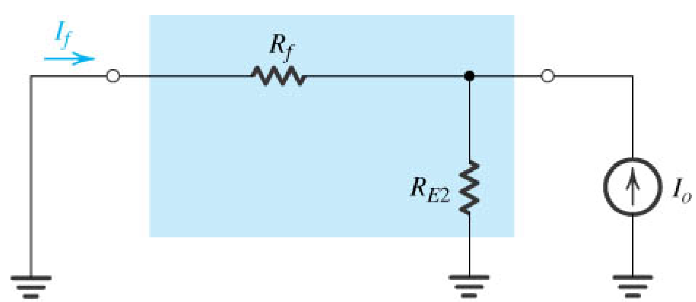


(c)

$$A = \frac{i_o}{i_i}$$

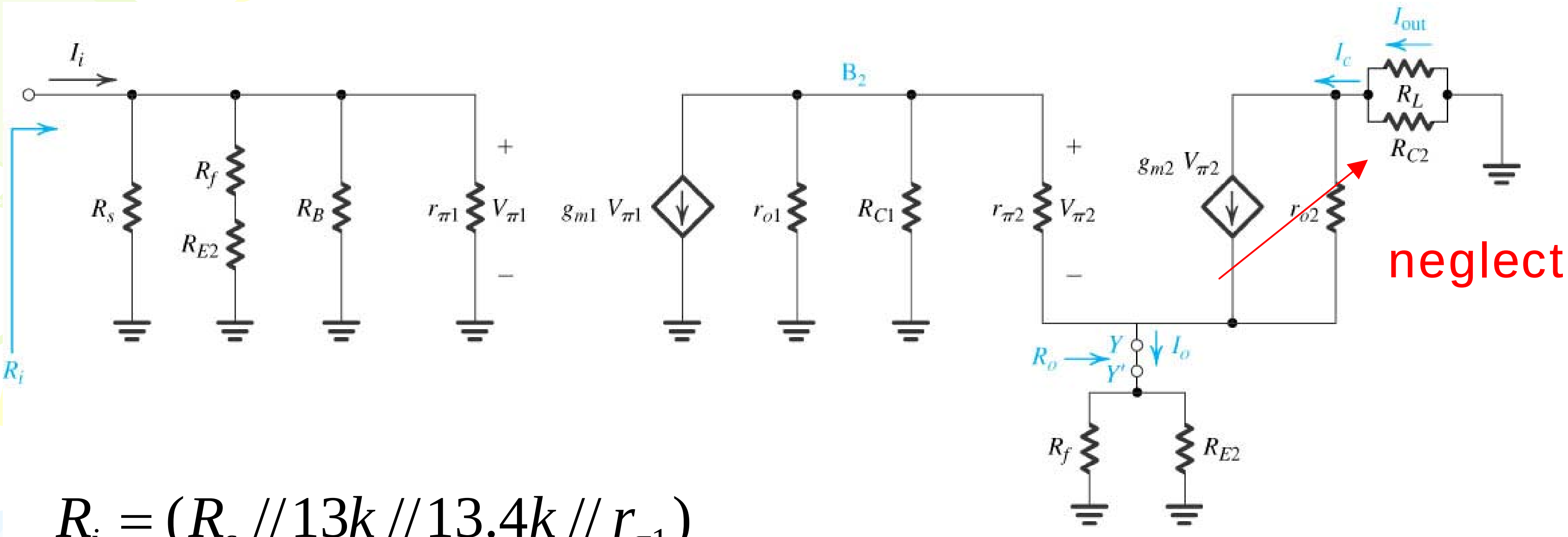
$$i_o = \frac{v_{c1}}{(r_e + 3.4k // 10k)} = \frac{-g_m v_{\pi 1}[10k // r_{o1} // (1+h_{fe})(r_e + 3.4k // 10k)]}{(r_e + 3.4k // 10k)}$$

$$i_i = \frac{v_{\pi 1}}{R_s // 13k // 13.4k // r_{\pi 1}}$$



(d)

$$\beta = g_{12} = \frac{i_1}{i_2}\bigg|_{v_1=0} = \frac{i_f}{i_o} = \frac{R_{E2}}{R_{E2} + R_f}$$



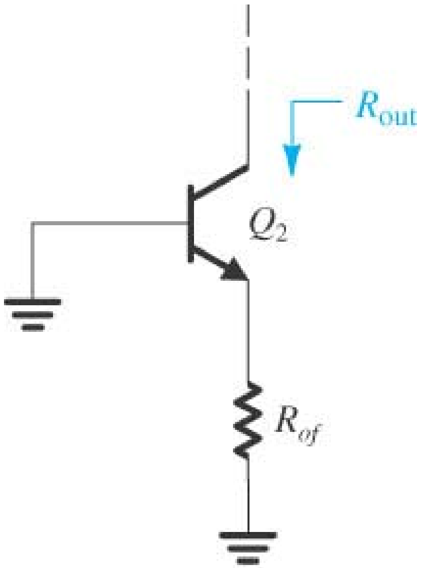
$$R_i = (R_s // 13k // 13.4k // r_{\pi 1})$$

(c)

$$R_{if} = \frac{R_i}{1+\beta A}$$

$$R_o = r_{e2} + (3.4k // 10k) + \frac{r_{o1} // 10k}{1+h_{fe}}$$

$$R_{of} = (1+\beta A)R_o$$



(e)